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HOL-GAR MODEL SP-HF-15, 15-KW,
400-HERTZ ENGINE GENERATOR SET

Howard L. Clark, Jr.

Army Mobility Equipment Research and
Development Center
Fort Belvoir, Virginia

May 1969

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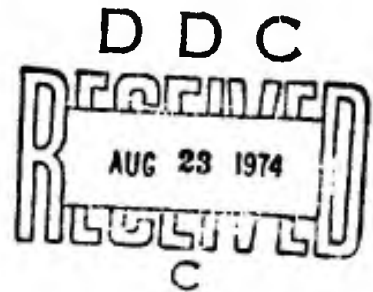
Report 1951

HOL-GAR MODEL SP-HF-15, 15-KW, 400-HERTZ

ENGINE GENERATOR SET

Task 1G664717D589-02

May 1969



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Prepared by

**Howard L. Clark
Power Equipment Division
Electrotechnology Laboratory**

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SUMMARY

This report covers the engineer design testing and evaluation of a 15-KW, 400-Hertz (Hz), compression-ignition, engine-driven generator set developed and manufactured by Hol-Gar Manufacturing Company, Inc., Primos, Pennsylvania, for use with the Army, 30-inch, Xenon Searchlight.

This report concludes that the generator set will be suitable for use with the Army, 30-inch, Xenon Searchlight.

FOREWORD

Authority for the investigation covered in this report is contained in Project Manager, Mobile Electric Power, letter dated 6 March 1967, to the U. S. Army Mobility Equipment Research and Development Center (MERDC).

The investigation was made from October 1967 through March 1968.

The work was accomplished by the following MERDC personnel:

Mr. C. E. Guthrie, Chief, Power Systems Branch.

Mr. H. L. Clark, Jr., Project Engineer.

Mr. J. W. Vinson, Electrical Engineering Technician.

Mr. B. W. Swearingen, Electrical Engineering Technician.

All work was done under the supervision of Mr. George F. Sams, Acting Chief, Power Equipment Division, and under the direction of Mr. T. G. Kirkland, Acting Chief, Electrotechnology Laboratory, MERDC.

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HOL-GAR MODEL SP-HF-15, 15-KW, 400-HERTZ

ENGINE GENERATOR SET

I. INTRODUCTION

1. Subject. This report covers the Engineer Design Tests of a 15-KW, 400-Hz, diesel-engine-driven, wheel-mounted generator set, Model SP-HF-15, designed and built by the Hol-Gar Manufacturing Corporation, Primos, Pennsylvania, to meet the requirements of the MERDC Purchase Description, "Generator Set, Compression-Ignition, Engine-Driven, 15-KW, Alternating-Current, Liquid-Cooled, Portable, Skid-Mounted, Multipurpose," dated 15 March 1967. The complete unit is shown in Figs. 1 through 3.

2. Background. A conference was held 14 February 1967, between the Army Materiel Command (AMC) Project Manager—Night Vision, AMC Project Manager—Mobile Electric Power (PM-MEP) and MERDC personnel at which time a requirement was established for a generator set to power the 30-inch, Xenon Searchlight. PM-MEP letter, dated 6 March 1967, to MERDC placed the requirement on MERDC to award and administer a contract for two hundred 15-KW, 400-Hz, special-purpose generator sets for use with the Xenon Searchlight.

In accordance with the requirement, a contract was awarded on 18 April 1967 to the Hol-Gar Manufacturing Corporation for the development-production of two hundred 15-KW, 400-Hz, special-purpose, diesel-engine-driven generator sets.

II. INVESTIGATION AND EVALUATION

3. Equipment Description. The diesel-engine-driven generator set consists of components (as listed in the following paragraphs) assembled into a weather-resistant housing. The set is attached to a 2-wheel, wheel mount for transportability.

Even though the set is "special purpose," maximum use of military standard components was made.

The set is permanently connected for 120/208-V, 4-wire output. The output of the set may be obtained from load terminals mounted inside of the set housing or through a 4-pin, MS3102E-32-17S receptacle mounted on the control-panel end. The set, rated for 15-KW, is instrumented in such a way that the 100 percent rated load current mark on the control panel ammeter is obtained with a 20-KW, 0.94-pf (lagging)

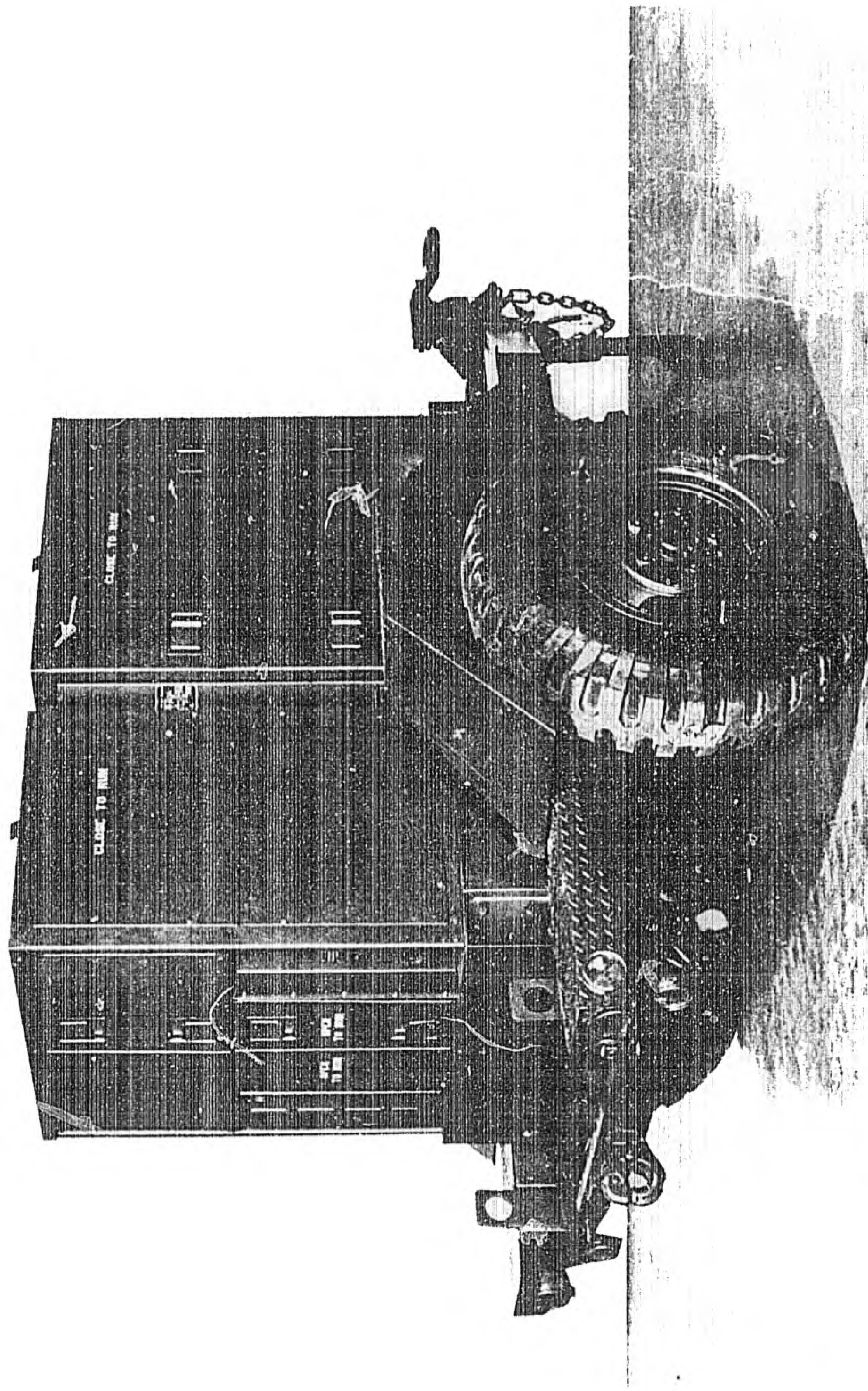
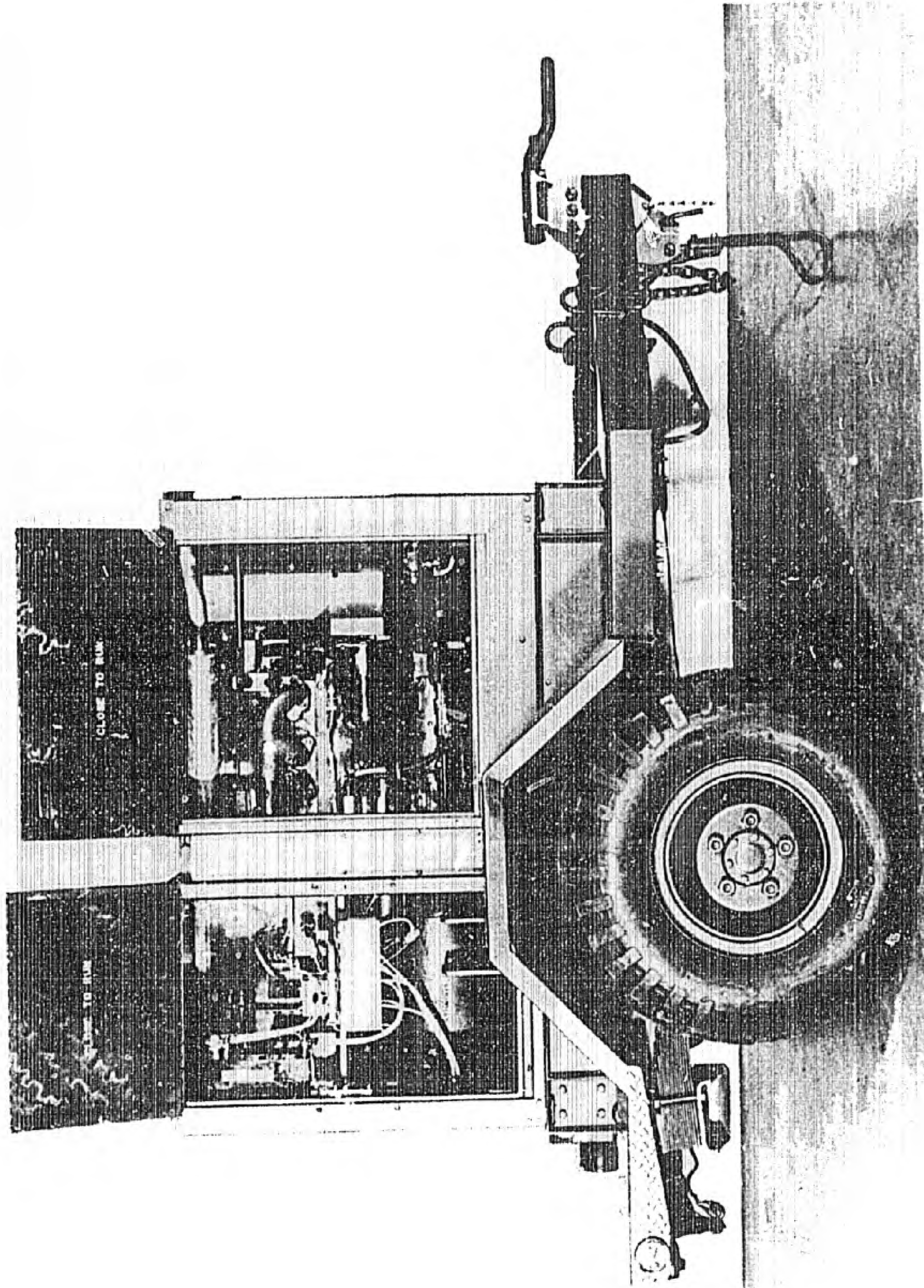
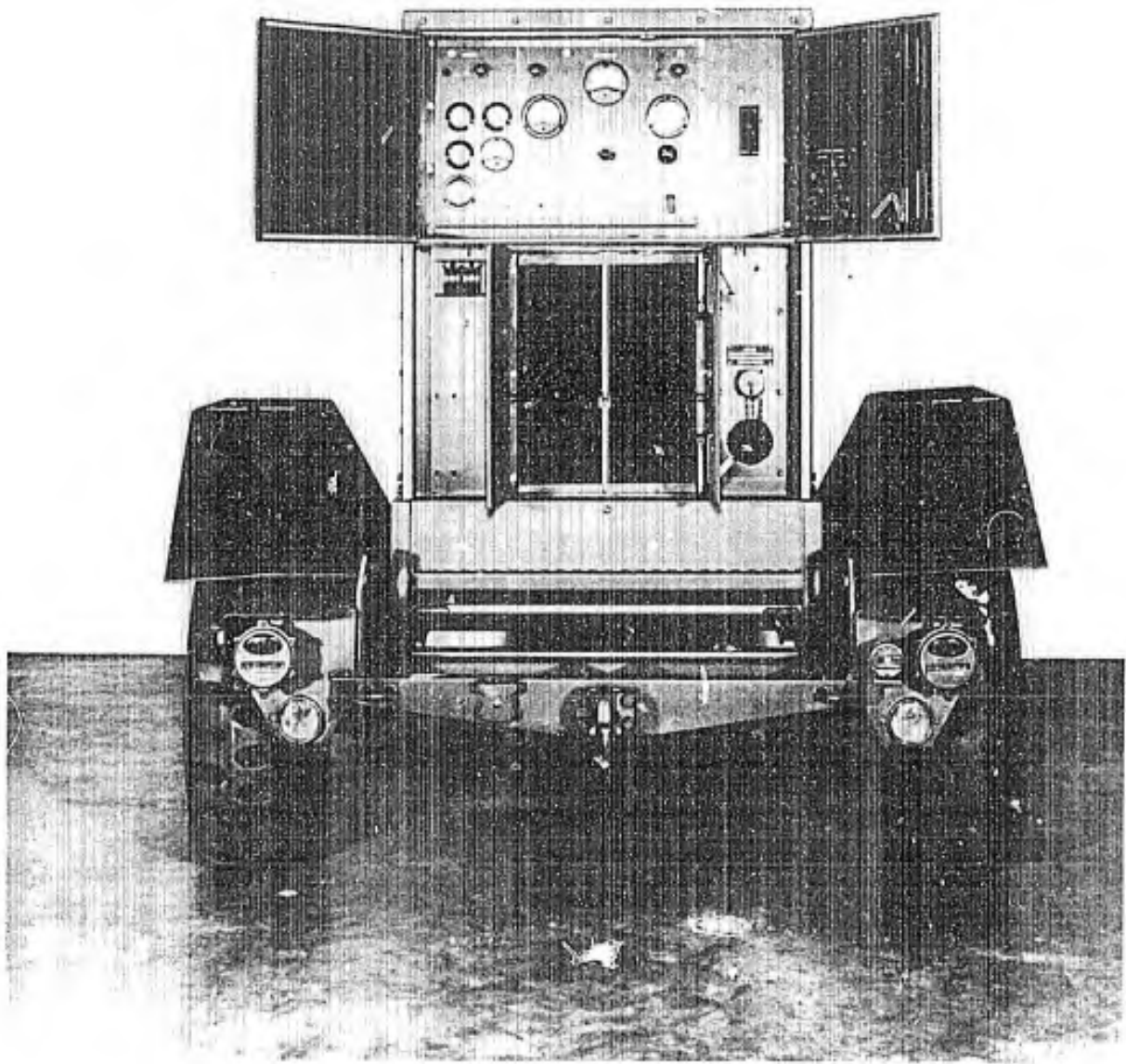


Fig. 1. Hol-Gar Model, SP-11F-15 Generator Set—Right, Three-Quarter View.



P10914

Fig. 2. Hol-Gar Model, SP-11F-15 Generator Set—Right-Side View.



P10910

Fig. 3. Hol-Gar Model, SP-HF-15 Generator Set—View from Control Panel End.

load connected to the set. This condition is necessary for compatibility with the power requirements of the Xenon Searchlight.

a. Diesel Engine. The diesel engine is a 4-cylinder Hercules Engine Company Model D198ERX28. The engine flywheel is coupled directly to the generator through flexible discs to drive the generator at engine speed. The engine-generator system speed is 1846 rpm for a rated frequency of 400 Hz. The engine is cranked by an electrical starting motor. The engine oil pump gear assembly drives the fuel-injection pump, and the tachometer output shaft drives the overspeed switch.

b. Alternator. The 400-Hz alternator is nominally rated at 15-KW, 0.80-power factor (pf) lagging, 1846 rpm. The alternator has a rotating field which is connected through slip rings to a static (no moving parts) exciter that supplies power to the field. The alternator is self-cooled by a ventilating fan mounted to the flexible-coupling discs.

c. Exciter. The exciter is a static, saturable-current-potential transformer type. Power for the exciter is taken from the alternator output and is rectified and supplied to the alternator field. The exciter has current feedback for quick response and for sustaining the required short-circuit current. The output of the exciter is controlled by the voltage regulator.

d. Voltage Regulator. The voltage regulator is a static, silicon-controlled rectifier type. Single-phase voltage sensing (phase three to neutral) is employed. The regulator output supplies current to the control winding of the saturable transformer in the exciter which, in turn, controls the alternator field excitation.

e. Instruments and Controls. The instruments and controls for the set are mounted on the control panel. The control panel is divided into two groups: engine and generator.

(1) Engine Group.

- (a) Oil pressure gage.
- (b) Coolant temperature gage.
- (c) Fuel level gage.
- (d) Battery charging ammeter.
- (e) Running time meter.
- (f) Ether primer switch.
- (g) Start-run-stop switch.
- (h) Panel light (1).

(2) Generator Group.

- (a) Frequency meter.
- (b) Percent rated current meter.
- (c) Voltmeter.
- (d) Voltmeter-ammeter selector switch.
- (e) Voltage adjustment rheostat.
- (f) Panel light switch.
- (g) D.C. control circuit breaker.
- (h) Protection bypass switch.
- (i) Panel light (2).

f. Battery. Two 12-volt, lead-acid batteries, type 6TN, connected in series furnish 24-volt, dc power to the engine starter motor and to the set control circuits. A slave receptacle is provided so that an external 24-volt, dc power source can be used as a starting aid or for charging the batteries.

g. Charging System. An MS 13823, 28-volt, 18-ampere rotating battery charging generator and an MS 13805 regulator are provided to charge the generator set batteries.

4. Equipment Identification List.

a. Generator Set.

Manufacturer	Hol-Gar Manufacturing Corporation.
Type	Special Purpose.
Model	SP-HF-15.
FSN	6115-089-5099.

	<u>Wheel Mounted</u>	<u>Demounted</u>
Length	127 in.	65 in.
Width	73 in.	34 in.
Height	75 in.	52 in.
Weight (operating)	3545 lb.	2525 lb.

b. Engine.

Manufacturer	Hercules Engines, Incorporated (A subsidiary of White Motor Corp.).
Type	Diesel.

Model	D198ERX28.
Speed	1846 rpm.
Lube Oil Specification	MIL-O-2104.
Oil Sump Capacity	6 qt.
Fuel	VV-F-800.

c. Alternator.

Manufacturer	Electric Machinery Manufacturing Co.
Type	Rotating Field
Model	Military Standard.
Part Number	13205E4607.
Excitation	Static.
Volts and Distribution	120/208-V, 3-phase, 4-wire.
Frequency	400 Hertz.
Operating Speed	1846 rpm.
Kilowatts	15.
Phase	1 and 3.
Pf	0.80 Lagging.
Poles	26.

d. Exciter.

Manufacturer	Electric Machinery Manufacturing Co.
Type	Static, saturable current-potential.
Model	Military Standard.
Part Number	13205E4616.

e. Voltage Regulator.

Manufacturer	Electric Machinery Manufacturing Co.
Type	Static, silicon-controlled.
Part Number	13205E4617.

f. Governor and Fuel-Injection Pump.

Manufacturer	Standard Screw Company, Hartford Div.
Type	Mechanical.
Model	DB.

g. Circuit Breaker.

Manufacturer	Federal Pacific Electric Company.
Type	J-frame.
Part Number	NFJ631100.

5. Test Procedure and Results. Tests were conducted in accordance with Military Standard MIL-STD 705-A, 5 March 1963, and Military Handbook MIL-HDBK-705, 17 October 1958, where applicable. Normal, ambient tests were performed on set serial number GB-67-0001 while environmental and endurance tests were performed on set serial number GB-67-0002. Generator dynamometer tests were performed on generator serial number GB-70150003. All tests were conducted by MERDC personnel at MERDC. Table I summarizes test results at normal, ambient conditions; Table II summarizes test results for various other ambient conditions; Table III summarizes normal, ambient dynamometer tests conducted on the alternator. Actual test data are on file at MERDC. Pertinent comments concerning some of the tests follow. (Where the term "full load" is employed in this report, it refers to 20 KW at 0.94 pf, lagging.)

a. Start and Stop Test. Throughout the test period, the set started and stopped in a normal manner without difficulty.

b. Ceiling Voltage. This test was performed to determine the set ceiling voltage with both a cold generator field and a hot generator field. The data obtained is only for information because there is no specification requirement for a minimum or maximum ceiling voltage. It was accomplished by disconnecting the voltage regulator and allowing excitation (and alternator output voltage) to rise to its maximum value.

c. Reverse Battery Polarity Protection. For this test, the set batteries were connected in reverse polarity; that is, the positive cable was connected to the negative battery terminal and the negative cable, to the positive battery terminal. Under this condition, the set would not crank and no damage occurred within the set.

d. Undervoltage Protection. Action of the undervoltage-protection device was demonstrated by reducing the set output voltage in steps until the main circuit breaker opened. The breaker did not trip until the voltage dropped to 55 volts (45% of rated value). This value is considered to be satisfactory.

e. Engine, Low-Oil-Pressure Protection. The plumbing for the lubricating oil system was arranged so that pressure at the Low Lube Oil Pressure Switch could be reduced without reducing the lubricating oil pressure within the engine. When the oil pressure to the switch was reduced to 15 psig, the set shut down. This indicated satisfactory design and operation of the low-oil-pressure protection system.

Table I. Summary of Test Results at Normal, Ambient, Sea-Level Conditions

Test	Test Results	Requirements	Compliance
1. Ceiling Voltage at No Load a. Cold Field b. Hot Field	169.5 Volts L-N 166 Volts L-N	No Requirement No Requirement	— —
2. Reverse Battery Polarity Protection	Set would not crank with battery cables connected in reverse. No damage to the set.	Set shall not crank and no damage shall occur within the set.	Yes
3. Undervoltage Protection	Circuit Interrupter tripped when voltage reached 45% of rated value.	Circuit Interrupter shall trip at approximately 50% of rated voltage.	Yes
4. Engine, Low-Oil-Pressure Protection	Set shut down when engine oil pressure reached 15 psig.	Set shall shut down when oil pressure reaches 10 to 15 psig.	Yes
5. Overspeed Operation	Set ran at 125% rated speed with no damage for 15 minutes.	Set shall be capable of running at 125% rated speed without any damage for 5 minutes.	Yes
6. Overspeed Protection	Set stopped when set reached 118% rated speed	Set shall shut down between 115 and 125% rated speed.	Yes
7. Voltage Unbalance with Unbalanced Load	1.92%	5%	Yes

Table I (cont'd)

Test	Test Results	Requirements	Compliance
8. Phase Balance (120/208-V connection) a. L-L b. L-N	Negligible voltage unbalance Negligible voltage unbalance	1% voltage unbalance 1% voltage unbalance	Yes Yes
9. Overvoltage Protection	Device tripped and the set shut down when the voltage reached 125% rated voltage.	Device shall trip and shut down the engine when the voltage reaches 125% of rated value.	Yes
10. Phase Rotation	A-B-C or 1-2-3	1-2-3 or A-B-C at output terminals and output receptacle.	Yes
11. Voltage Regulation	0.98%	1%	Yes
12. Frequency Regulation	3.2%	5%	Yes
13. High Coolant Protection	Set stopped when coolant temperature reached 215° F.	Trip and shut down the set between 215° F and 220° F.	Yes
14. Start and Stop	Set started and stopped satisfactorily.	Set shall start and stop readily.	Yes
15. Maximum Power	26.8 KW	No Requirement	—

Table I (cont'd)

Test	Test Results	Requirements	Compliance
16. Governor Stability and Transient Response			
a. Maximum frequency transient on application of full load.	1.48%	6%	Yes
b. Maximum frequency recovery time on application of full load.	0.5 sec	4 sec	Yes
c. Maximum frequency variation at constant load.	± 0.5 Hz	± 4 Hz	Yes
d. Maximum frequency transient on rejection of full load.	1.25%	6%	Yes
e. Maximum frequency recovery time on rejection of full load.	0.5 sec	4 sec	Yes

Table II. Summary of Test Results for Various Other Ambient Conditions

Test	Ambient Condition				Specification Requirements	Compliance
	125° F Sea Level	95° F 8,000 Ft	110° F 3,000 Ft	25° F Sea Level		
1. Governor Performance						
a. Maximum frequency transient on application of full load	0.5%	0%	0.37%	1.0%	6%	Yes
b. Maximum frequency recovery time on application of full load	0.5 sec	0.7 sec	0.5 sec	0.4 sec	4 sec	Yes
c. Maximum frequency variation at constant load	± 0.5 Hz	± 0.5 Hz	± 0.5 Hz	± 0.75 Hz	± 4 Hz	Yes
d. Maximum frequency transient on rejection of full load	0.81%	0.25%	0%	1.25%	6%	Yes
e. Maximum frequency recovery time on rejection of full load	0.3 sec	0.5 sec	Negligible	0.6 sec	4 sec	Yes
2. Regulation						
a. Voltage	Negligible	Negligible	Negligible	N. g. lible	1%	Yes
b. Frequency	2.3%	2.5%	2.5%	2.17%	Up to 5%	Yes
3. Maximum Power	24.8 KW	22 KW	24.8 KW	—	None	—
4. Range of voltage adjustment						
a. No load	111-152 V	—	111-152 V	107-145 V	114-128 V	Yes
b. Full load	111-150 V	—	111-150 V	109-145 V	114-128 V	Yes
5. Start and stop	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Yes

Table III. Summary of Dynamometer Tests Conducted at Normal Ambient

Test	Results		Requirements (For 3-phase only)	Compliance
	Single Phase*	3-Phase		
1. Efficiency	85%	86%	—	—
2. Direct Axis Transient Reactance	20.2%	10.45%	14%	Yes
3. Negative Sequence Reactance	**	8.34%	9%	Yes
4. Regulator Stability and Transient Response				
a. Maximum voltage transient on application of full load.	15%	10.0%	12%	Yes
b. Maximum voltage recovery time on application of full load.	150 msec	95 msec	150 msec	Yes
c. Maximum voltage variation at constant load.	Negligible	Negligible	0.5%	Yes
d. Maximum voltage transient on rejection of full load.	16.5%	9.5%	12%	Yes
e. Maximum voltage recovery time on rejection of full load.	185 msec	95 msec	150 msec	Yes
f. Maximum voltage transient on application of two PU zero pf load.	28%	18.5%	25%	Yes
g. Maximum voltage recovery time on application of two PU zero pf load.	160 msec	135 msec	700 msec	Yes
h. Maximum voltage transient on rejection of two PU zero pf load.	34%	19%	25%	Yes
i. Maximum voltage recovery time on rejection of two PU zero pf load.	275 msec	135 msec	700 msec	Yes
5. Voltage regulation	Negligible	Negligible	1.0%	Yes

* No requirements are placed on single-phase operation. Tests were conducted for information.

** This test is a 3-phase-only test.

f. Overspeed Operation. The set was run at no load at 500 Hz (125 percent rated speed) for 5 minutes. No trouble occurred during this test.

g. Overspeed Protection. The set speed was increased until the overspeed protection device stopped the set. The overspeed switch actuated, and the set stopped when the output frequency reached 472 Hz thus conforming to the Purchase Description requirement that the device shut down the set when the frequency reaches between 460 and 500 Hz.

h. Voltage Unbalance with Unbalanced Load. A single-phase, unity-pf load drawing approximately 26 percent rated current (for a 15-KW, 0.80-pf base) was applied line-to-line. The voltages and currents, shown in Table IV, were recorded with the set connected for 120/208-V output.

From Table IV, calculations show that the maximum difference in line-to-line voltages, expressed as a percentage of rated line-to-line voltage, was 1.92 percent. The maximum difference in line-to-neutral voltages, expressed as a percentage of rated line-to-neutral voltage, was 1.84 percent. These values are within the 5 percent maximum unbalanced voltage permitted by the Purchase Description.

Table IV. Load Unbalance Test Results

Voltage L-N (V)	Voltage L-L (V)	Current (a)
L ₁ - N -- 122.0	L ₁ - L ₂ -- 212.0	0.0
L ₂ - N -- 122.2	L ₂ - L ₃ -- 209.5	13.6
L ₃ - N -- 120.0	L ₃ - L ₁ -- 209.0	13.6
L ₁ - N -- 117.8	L ₁ - L ₂ -- 206.0	13.6
L ₂ - N -- 120.0	L ₂ - L ₃ -- 208.5	0.0
L ₃ - N -- 120.0	L ₃ - L ₁ -- 206.0	13.6
L ₁ - N -- 120.0	L ₁ - L ₂ -- 206.0	13.6
L ₂ - N -- 118.5	L ₂ - L ₃ -- 206.0	13.6
L ₃ - N -- 120.0	L ₃ - L ₁ -- 210.0	0.0

i. Phase Balance. This test was conducted at no load, with the set connected for 120/208-V output: The set is permanently connected for this voltage. Results of the test shown in Table V indicate that the phase balance requirement of 1 percent was met.

Table V. Phase Balance Test Results

Line-to-Neutral Voltage	Line-to-Line Voltage
$L_1 - L_n$ -- 119.6	$L_1 - L_2$ -- 208.0
$L_2 - L_n$ -- 119.7	$L_2 - L_3$ -- 208.0
$L_3 - L_n$ -- 119.6	$L_3 - L_1$ -- 208.0

j. Overvoltage Protection. This test was performed by increasing the set output voltage until the overvoltage device actuated. The device actuated when the voltage, as measured by an indicating meter, reached 150 volts or 125 percent of rated voltage, thus meeting the requirements of the Purchase Description.

k. Phase Rotation. Phase rotation of the set at the output terminals and the output receptacle was checked and found to be " L_1 " - " L_2 " - " L_3 " and "A" - "B" - "C" respectively; this is in conformance with the Purchase Description requirements.

l. High Coolant Protection. This test was performed by closing the set air intake and allowing the engine temperature to increase. The set stopped when the engine coolant reached 215° F. This operation conforms to the Purchase Description requirements.

m. Voltage Regulation. The voltage regulation test was performed using a laboratory-type, indicating voltmeter and the voltage regulation was found to be 0.98 percent. This conforms to the requirements of the Purchase Description of 1.0 percent (maximum).

n. Frequency Regulation. The frequency regulation test was performed using a laboratory-type, indicating frequency meter. The regulation was found to be 3.2 percent which conformed to the requirements of the Purchase Description that the frequency regulation be between 3 and 5 percent.

o. **Voltage Waveform.** A harmonic analysis was made on the output of the set. The data is summarized in Table VI. The data indicates that the requirement that no single harmonic shall exceed 2 percent of the fundamental was met.

Table VI. Results of Harmonic Analysis Test

Harmonic No.	Percentage of Fundamental					
	Line-To-Neutral Voltage (L3 - LN)			Line-To-Line Voltage (L1 - L3)		
	No Load	20-KW, 0.94-pf lag	20-KW, 1.0-pf	No Load	20-KW, 0.94-pf lag	20-KW, 1.0-pf
1	100.0	100.0	100.0	100.0	100.0	100.0
2	0.08	0.069	0.095	0.07	0.095	0.06
3	0.90	1.30	1.25	0.85	1.25	1.24
5	1.25	0.59	0.58	1.30	0.58	0.54
7	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0
11	0.30	0.38	0.34	0.35	0.33	0.28
13	0.26	0.20	0.20	0.24	0.20	0.29
15	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0

p. **Rough Handling.** The rough handling test was divided into two parts: The lift test and the railroad hump test. Comments on the two tests are as follows:

(1) **Lift Test.** The lift test was performed with the wheel mount removed from the generator set and the set firmly attached to a railroad flat car. A vertical force was applied to the set lifting clevis by a crane through a dynamometer scale. The Purchase Description requires the set to withstand a force of eight times the set weight which is 20,000 pounds. During the initial test, the set lifting structure ("A" frame) bowed in the center. The "A" frame was strengthened by the addition of a 3-inch "I" beam welded on the underside of its center member. The test was repeated with the modified "A" frame, and the requirements of the Purchase Description were met.

The vertical force was increased to approximately 28,000 pounds to simulate eight times the combined set and wheel-mount weight. With this force applied, there was a slight bow in the center of the "A" frame. This force was not a specification requirement but was applied to determine the ability of the set lifting structure to lift the set and wheel-mount combination. Even with the slight bow, the structure is considered suitable for lifting the combination.

(2) Railroad Hump Test. The railroad hump test was performed with the set and wheel-mount combination mounted to a railroad flat car. The combination was tied to the car by cables through the tie-down loops on the wheel-mount frame. Also, the wheels were blocked. The Purchase Description required the set to withstand hump speeds up to and including 10 miles per hour.

During the initial attempt, the tie-down loops on the wheel mount failed and damage resulted to the wheel mount. The tie-down loops were relocated on the wheel-mount frame. For the second attempt, the relocated tie-down loops on the wheel mount and the towing eyes on the control-panel end of the generator set were used for tying the combination to the railroad flat car. The wheels were also blocked. The hump test was repeated, and the requirements of the Purchase Description were met.

The wheel mounts were removed and the generator set was humped. The only damage was failure of a weld at the bottom, horizontal member of the radiator-protective grill and slight deformation of the front corner post. Neither of these conditions would interfere with the ability of the unit to perform its intended function.

q. Electromagnetic Compatibility. The set was tested in accordance with Military Specification MIL-E-55301 by personnel of the Components Branch of the Power Equipment Division. The test report indicated that the set met the requirements of Specification MIL-E-55301.

r. Audio Noise Test. The audio noise test was conducted at MERDC by personnel of the Components Branch of the Power Equipment Division. Results of the test indicated that the sound levels emitted by the set are well within the requirements of the Purchase Description.

s. Endurance. A 1500-hour endurance test was made on the set at MERDC. All operation during the endurance test was accomplished out of doors with the set exposed to the sun, wind, rain, and snow. The test was conducted from 5 December 1967 to 1 March 1968. During the endurance run, the set was operated on the wheel mount for the entire period. Operation of the set was continually monitored with electrical

and thermal data being recorded. Servicing consisted of lube oil change, lube oil filter change, fuel filter changes, and cleaning the fuel pump strainer every 100 hours. During the first 915 hours, the set was loaded in accordance with the load schedule of method 690.1b of Mil-Std 705. For the remaining 585 hours, the set was loaded to 22 KW with a resistive load or by the Xenon Searchlight. Operation of the set with the 22-KW resistive load simulated the approximate load of the searchlight. During operation with the searchlight, the frequency stability was affected by load variations within the searchlight (as much as 1.0 KW); thus, the frequency of the generator varied accordingly but remained within the Purchase Description requirement of ± 0.5 percent.

During the endurance test, several problems occurred which are listed in Table VII with the necessary corrective action taken.

An explanation of the problems listed in Table VII follows.

(1) Water Separator Failure. The set is equipped with an automatic water separation system which removes any water in the fuel before it enters the set day tank. As water accumulates in the separator, a magnetic float which senses the interface between the fuel and water rises to a point where it actuates a reed switch. This switch, a single-pole, double-throw arrangement, energizes the water dump solenoid valve and de-energizes the fuel-intake solenoid valve to the day tank. During the endurance test, water was intentionally added to the fuel supply to determine the reliability of the separator system. At the beginning of the test, it was determined that the separator was passing water into the day tank. Investigation revealed that the drums used for the fuel supply had been previously used to store anti-freeze. It was learned from the separator manufacturer that one part per million of ethylene glycol—the substance in anti-freeze—would destroy the coalescing action of the separator element. After the fuel supply was cleaned, the separation system worked properly for approximately 600 hours. At the 600-hour point, the system continued to dump fuel after all of the water had been separated. The reed switch contacts had become pitted and welded in the dump position. A new separator was installed and was operated for approximately 25 hours. Again, the switch welded in the dump position. Investigation by MERDC and the switch manufacturer revealed that five out of six switches had been damaged by overloading (apparently some time before installation into the generator sets). The water separator system will perform properly if it is not damaged by overload and the separator element coalescing action is not destroyed by foreign matter in the fuel.

(2) Fuel-Injection Pump Failure. After approximately 100 hours of endurance operation, a gradual deterioration of steady-state frequency regulation was observed. Inspection of the pump revealed that the thrust spring between the

Table VII. Problems Incurred During the 1500-Hour Endurance Test

Problem	First Noted or Reported (Hr into test)	Corrective Action
Water separator passing water into day tank.	45	Replaced separator element and cleaned anti-freeze from fuel drums.
Fuel-injection pump—poor steady-state frequency regulation.	100	Changed injection pumps. Also changed from a check valve to a ported, valve-type pump on recommendation of pump manufacturers for better frequency stability.
Generator fan failure.	123	Replaced the spot-welded fan with a spot-welded and riveted fan.
Set shut down because of low fuel.	198	Found fuel pump strainer clogged. Cleaned strainers. Included in 100-hour service to clean pump strainers.
Fuel-transfer pump failure.	220	Replaced fuel pump. (Considered a random failure.)
Injection pump, oil pump, and cam shaft failure.	296	Installed new injection pump, oil pump, and cam shaft. Corrective action: none. (Considered a random failure.)
Fuel-injection pump leaking at injection line fittings.	431	Replaced steel washers with copper washers for better seating.
Water separator failure.	628	Replaced water separator. No corrective action taken. (Considered a random failure.)
Unstable frequency.	646	Cleaned fuel-injection pump and installed thrust spring in the end of drive shaft.
Water separator failure.	698	Replaced water separator. No corrective action taken.
Water separator failure.	706	Same as above.
Main circuit breaker failed to operate—would not close.	915	Malfunction corrected itself.
Overspeed switch tripped.	1034	Reset switch and continued to operate.
Overspeed switch tripped.	1037	Replaced overspeed switch. Corrective action: none. (Considered a random failure.)
Battery charger mounting bracket loose.	1353	Tightened bolts holding bracket to engine.
Overspeed switch tripped.	1454	No corrective action taken. (Considered a nuisance trip.)

pump drive shaft and the oil pump drive gear had been crushed. The spring was most likely damaged during installation of the pump on the engine. It is believed that the crushed spring caused abnormal deterioration of the pump performance due to increased thrust on the pump, thus causing rapid wear of pump parts.

At the 100-hour point, the pump manufacturer recommended substituting a ported-rotor pump for the original ball-check pump in order to obtain better steady-state frequency stability. This recommendation was accepted by MERDC.

A ported-rotor, injection pump was installed, and satisfactory governing was obtained.

After 296 hours of endurance testing, the newly installed ported pump seized. With the pump seizure, the engine lube oil pump and cam shaft were damaged beyond use. The three items were replaced. Inspection of the injection pump indicated that a fuel-injection-line connector screw had bottomed distorting the hydraulic head of the pump. The reason the screw bottomed is that a washer was omitted or a foreign particle was trapped below the connector screw tip during installation. With a new injection pump, lube oil pump, and cam shaft installed, satisfactory performance was obtained. For the next 650 hours of operation, the second ported pump performed satisfactorily. At the 1046-hour point, poor steady-state frequency regulation was observed again. Disassembly of the pump disclosed some parts with formation of rust. The rust formed because water entered the injection pump when the water separator failed. The pump was cleaned, reassembled, and reinstalled on the set. Performance was much improved, but after 50 hours of operation, the pump was removed from the set because of erratic operation. It was found that the thrust spring and "O" ring seal had been omitted when the pump was installed. The pump was reinstalled with the thrust spring and "O" ring seal. Performance was satisfactory for the remainder of the endurance test.

(3) Generator Fan Failure. The generator fan blades broke loose from the fan disc after 123 hours of operation. The blades were spot welded to the disc. The fan was replaced with a fan that had the blades both spot welded and riveted to the disc. No problems occurred for the remainder of the test.

(4) Low Fuel Shut Down. The set shut down at 198 hours of operation because of lack of fuel in the set day tank. Investigation revealed that the strainer in the fuel transfer pumps was clogged with foreign matter. This indicated that the strainer was functioning properly. The corrective action was to include cleaning of the pump strainer in the 100-hour service.

(5) Fuel-Transfer Pump Failure. After 220 hours of endurance operation, one of the two fuel-transfer pumps failed. This is considered a random failure.

(6) Main Circuit Breaker Failure. The main circuit breaker would not close after 915 hours of operation. The breaker was by-passed for approximately 100 hours of operation. When the main breaker was replaced, it operated satisfactorily and operated normally for the remainder of the test.

(7) Overspeed Switch Tripped. After 1034 hours of endurance operation, the overspeed switch tripped. The switch was reset and the set was restarted. After 3 more hours of operation, the overspeed switch tripped again. The switch was removed and a new switch was installed. The new switch tripped after an additional 100 hours of operation. Trips of both switches were considered random, and no corrective action was taken.

(8) Engine Deterioration. At approximately 1055 hours of operation, there was a gradual deterioration in engine performance. The engine exhaust began to smoke excessively and frequency would not recover readily on the application of a 22-KW load (with a "cold" engine). Once the engine did recover, it would carry 22 KW satisfactorily. After 1431 hours of endurance operation, the engine would only carry 20 KW which indicated a drop in maximum power from approximately 28 KW to 20 KW. The set continued to operate at a 20-KW load for the remainder of the 1500 hours at which time the engine was completely torn down and inspected. Prior to the disassembly of the engine, the fuel-injection-pump timing was checked. The timing was found to be at 12° BTDC rather than the specified value of 34° BTDC. This factor can account for the apparent deterioration in engine performance. It is not known why the timing was off by the amount indicated. It is surmised that the oil-pump drive was not properly installed when replaced after the injection-pump seizure (see paragraph 5s(2)).

During the first 296 hours of endurance operation, the set did not use lubricating oil between 100-hour services. After the installation of the new cam shaft, oil pump, and fuel injection pump (see paragraph 5s(2)), the oil pan gasket was not properly installed and a lube oil leak developed through no fault of the engine. During the remaining endurance test period--1200 hours--an average of 0.0264 quart per hour of oil was used. During the recording period, the oil consumption varied for any one specific period from 0.010 to 0.0386 quart per hour. This consumption indicates that most of the oil was leaking rather than being consumed by the engine. An accurate measurement of oil consumed by the engine could not be obtained.

Disassembly of the engine revealed that all of the engine parts were in excellent condition. No parts were replaced except those gaskets needed to rebuild the engine. A maximum power of 27.5 KW was obtained after reassembly of the engine and generator set. This confirms that the engine deterioration was due to improper timing.

t. Environmental Tests. Environmental tests were conducted in the environmental test chamber at MERDC. Tests were conducted in the range from sea level at -25°F , to sea level at 125°F , and to 8,000 ft at 95°F . The Purchase Description requires the set to operate only between sea level at 32°F and 3,000 ft at 110°F . However, the above range of tests was conducted to obtain information. No tests were conducted at temperatures lower than -25°F because no winterization system is included on the set. Environmental tests performed are listed in Table VIII.

Table VIII. Environmental Tests Performed

Test	Climatic Condition			
	Sea Level 125°F	Sea Level -25°F	8,000 Ft 95°F	3,000 Ft 110°F
Start and stop	X	X	X	X
Temperature stabilization	X	X	X	X
Frequency stability and transient response	X	X	X	X
Maximum power	X	—	X	X
Voltage and frequency regulation	X	X	X	X
Range of voltage adjustment	X	X	—	X

Pertinent information concerning environmental tests follows:

(1) Start and Stop. The set started and stopped satisfactorily during all of the environmental tests. At the sea-level, -25°F condition, an ether system was employed for starting. The ether system allows a metered amount of ether to enter the engine intake manifold when the ether primer switch on the set control panel is actuated during engine cranking. The switch must be actuated each time a shot of ether is needed. Approximately 10 to 15 shots of ether were required to obtain smooth engine operation. Prior to the set being started at sea-level, -25°F ,

the fuel solenoid was de-energized and the engine was cranked two times for 30 seconds each. This procedure was followed in order to determine whether or not the batteries had adequate capacity and to simulate cranking with partially charged batteries.

(2) Temperature Stabilization. No requirements for this test exist in the Purchase Description. This test was performed to determine whether long term operation under various conditions would be acceptable. Stabilized temperatures at certain significant points within the set are presented in Table IX.

Table IX. Temperature Stabilization Test Results in °F

Significant Point	Condition							
	-25° F, Sea Level		125° F, Sea Level		110° F, 3000 Ft		95° F, 8000 Ft	
	No Load	Full Load	No Load	Full Load	No Load	Full Load	No Load	Full Load
Coolant out of block	180	179	181	203	181	194	*	193
Coolant into block	164	159	170	199	167	189	*	187
Lube oil	185	89	213	229	210	219	*	218
Fuel in day tank	119	86	142	142	131	127	*	115
Air into set	-19	-26	125	127	112	111	*	95
Air into air cleaner	120	100	130	134	125	118	*	105
Exhaust	210	720	400	880	415	920	*	1025

*A no-load stabilization was not performed at this condition.

(3) Frequency Stability and Transient Response. Typical charts for the frequency stability and transient response are shown in Figs. 4 and 5.

(4) Maximum Power. This test was made at unity pf by loading the set to the maximum extent possible without letting the output speed fall below 380 Hz. This load was held for at least 5 minutes. Results of this test are given in Table X.

Table X. Results of Maximum Power Test

Condition	Maximum Power (KW)
Sea Level, Normal Ambient (72°)	26.8
3,000 ft, 110° F	24.8
8,000 ft, 95° F	22.0
Sea Level, 125° F	24.5

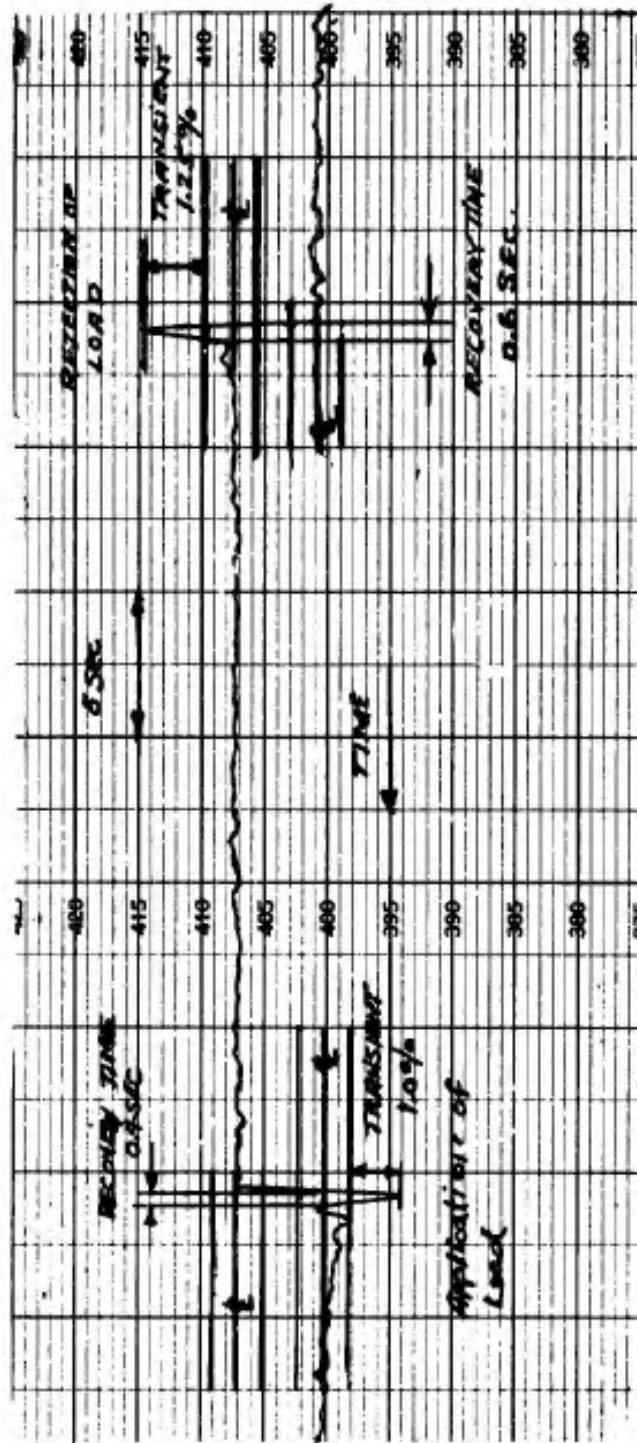


Fig. 4. Frequency stability and transient response at rated load, sea level, minus 25° F.

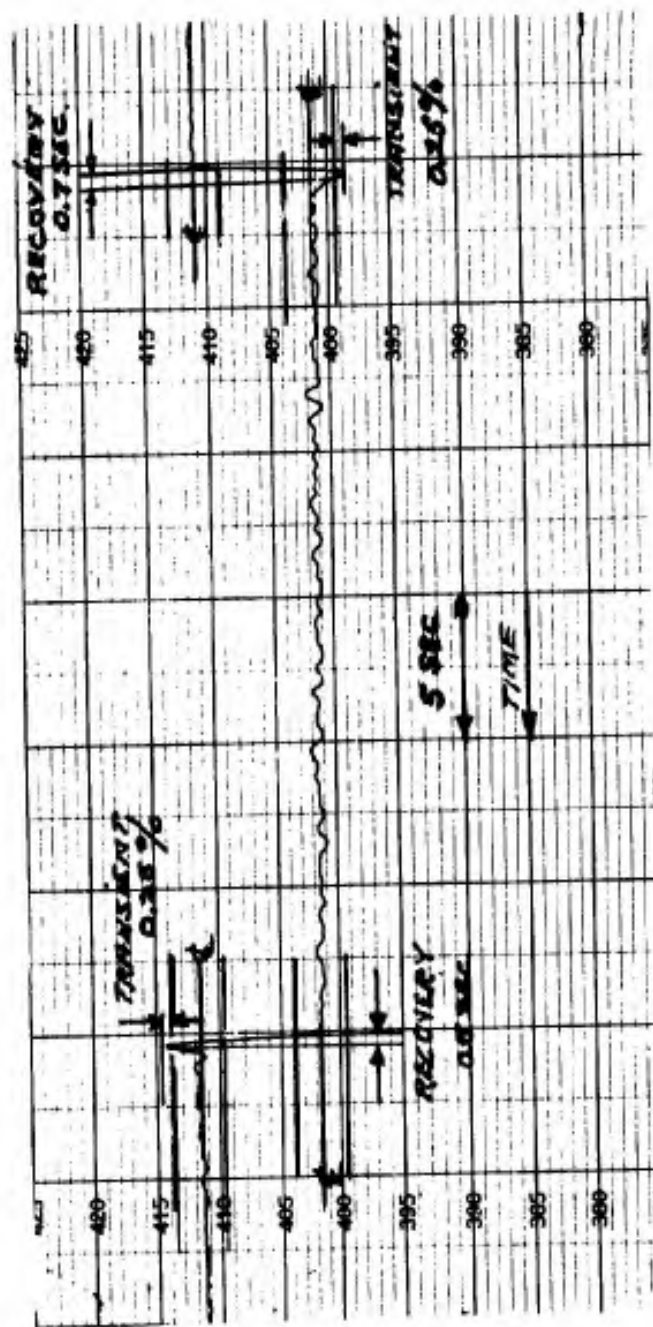


Fig. 5. Frequency stability and transient response at rated load, 8,000 Ft, 95° F.

(5) Voltage and Frequency Regulation. Results of this test indicating that the set complies with the Purchase Description are given in Table II.

(6) Range of Voltage Adjustment. Results of this test indicating that the set complies with the Purchase Description are given in Table II.

u. Motor-Starting Test. This test was performed to determine the motor-starting characteristics of the generator set. A Bogue Electric Manufacturing Company, 15-horsepower, 400-Hz, 3000-rpm, 3-phase, NEMA Code F, induction motor was used for the test. The three conditions under which tests were performed are as follows:

- (1) No load on the motor.
- (2) Inertia load on motor shaft equal to the motor's own inertia.
- (3) Inertia load on motor shaft equal to twice the motor's own inertia.

Figures 6, 7, and 8 present the results of this test. As seen in each figure, the voltage initially dropped to approximately 70 percent of rated voltage. As more inertia load was added to the motor, the frequency transient increased. The engine generator set was able to recover under all conditions without having any protective devices actuate. Also, the recovery time increased with an increase in motor load as shown in the figures. Since no requirement was specified in the Purchase Description, this test was conducted for information only.

v. Dynamometer Tests. These tests were conducted at MERDC by MERDC personnel. The requirements listed in Table III are for the 3-phase connections only. No requirements are placed on the generator for the single-phase connections which were conducted for information only. Full load for all the dynamometer tests was taken to be 15-KW, 0.80-pf (lagging). As can be seen in Table III, the generator met the requirements of the Purchase Description. Pertinent comments concerning the tests follow:

(1) Efficiency. The efficiency of the generator was determined at both the single-phase and 3-phase connections. The results of this test are shown in Figs. 9 and 10. During this test, separate excitations were used for the alternator field. The alternator was loaded at 0.80-pf and the output determined by wattmeter readings. The input was the sum of power measurements made for the rotating field (voltage and current) and the dynamometer indication (pounds pull and speed).

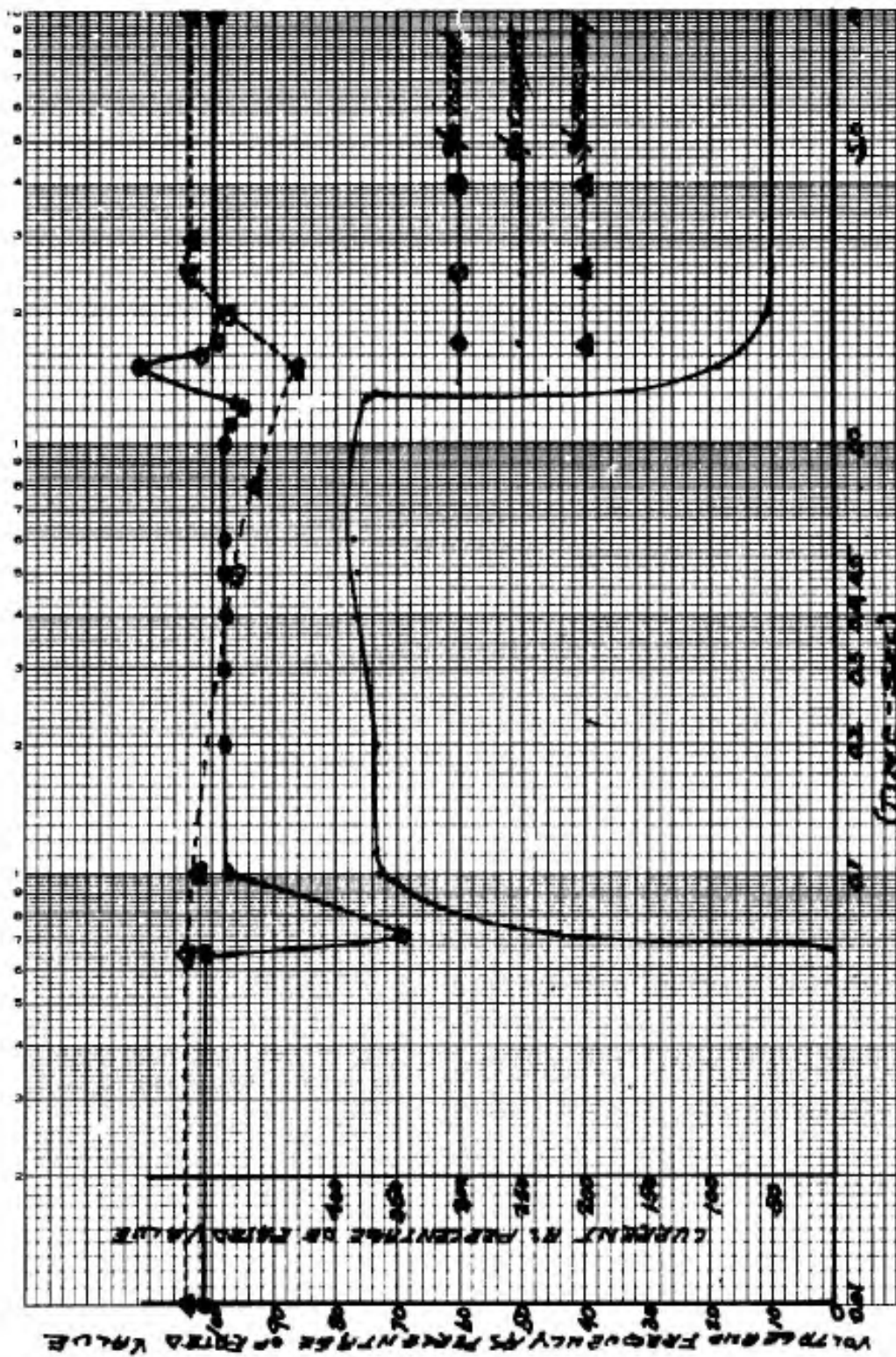


Fig. 6. motor-start test --- no load on motor.

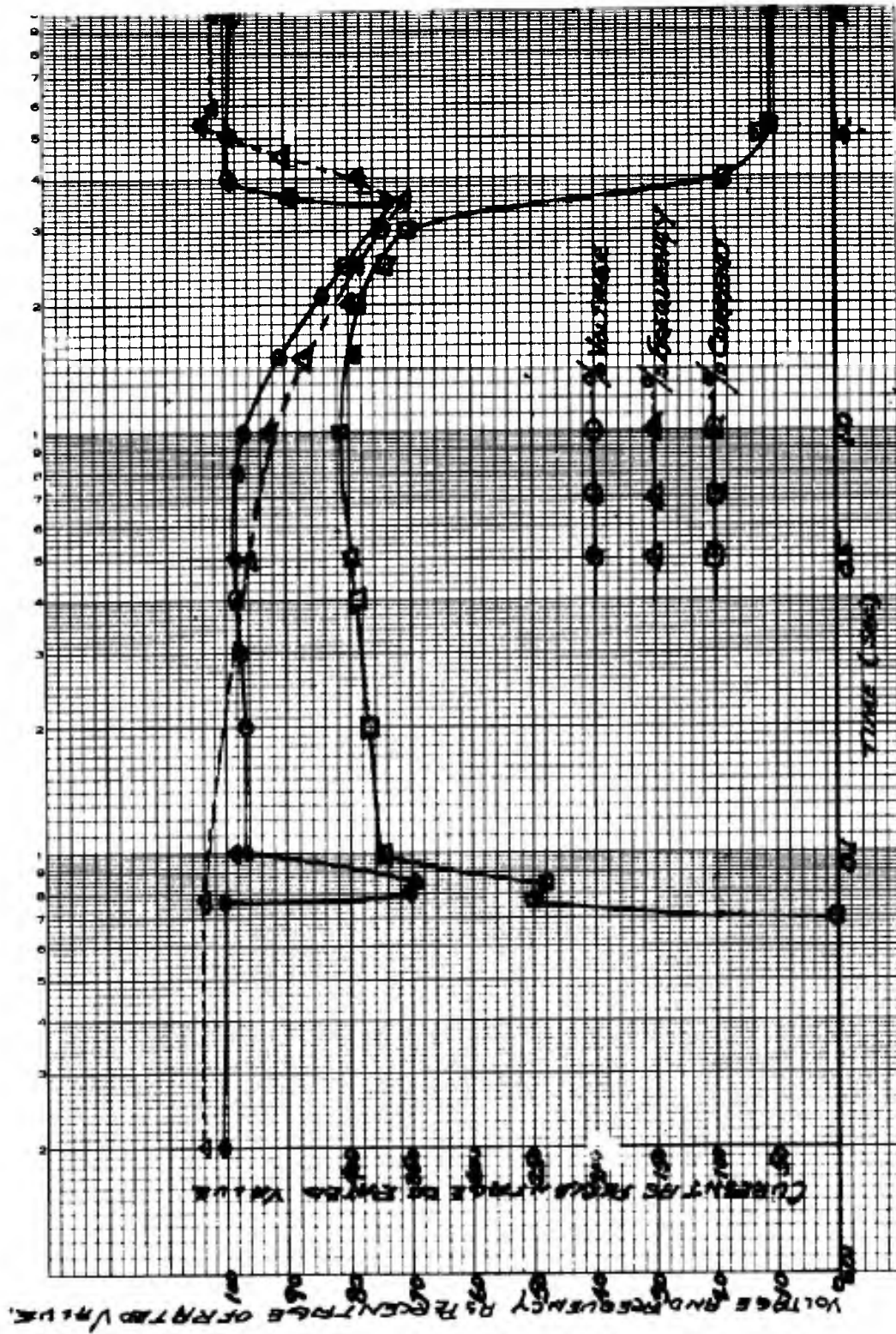


Fig. 7. Motor-start test— inertia load equal to motor inertia.

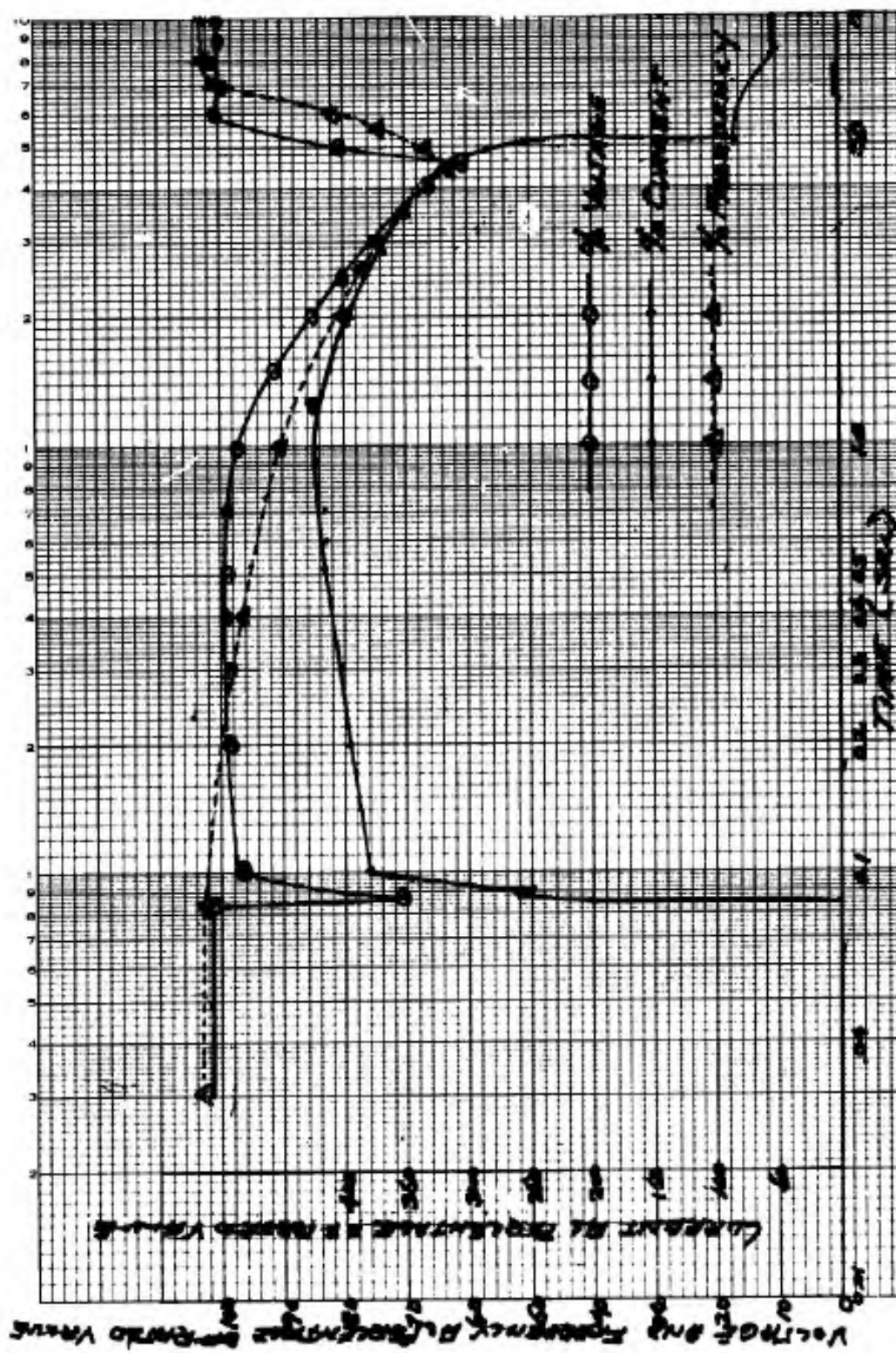


Fig. 8. Motor start test ---inertia load equal to twice motor inertia.

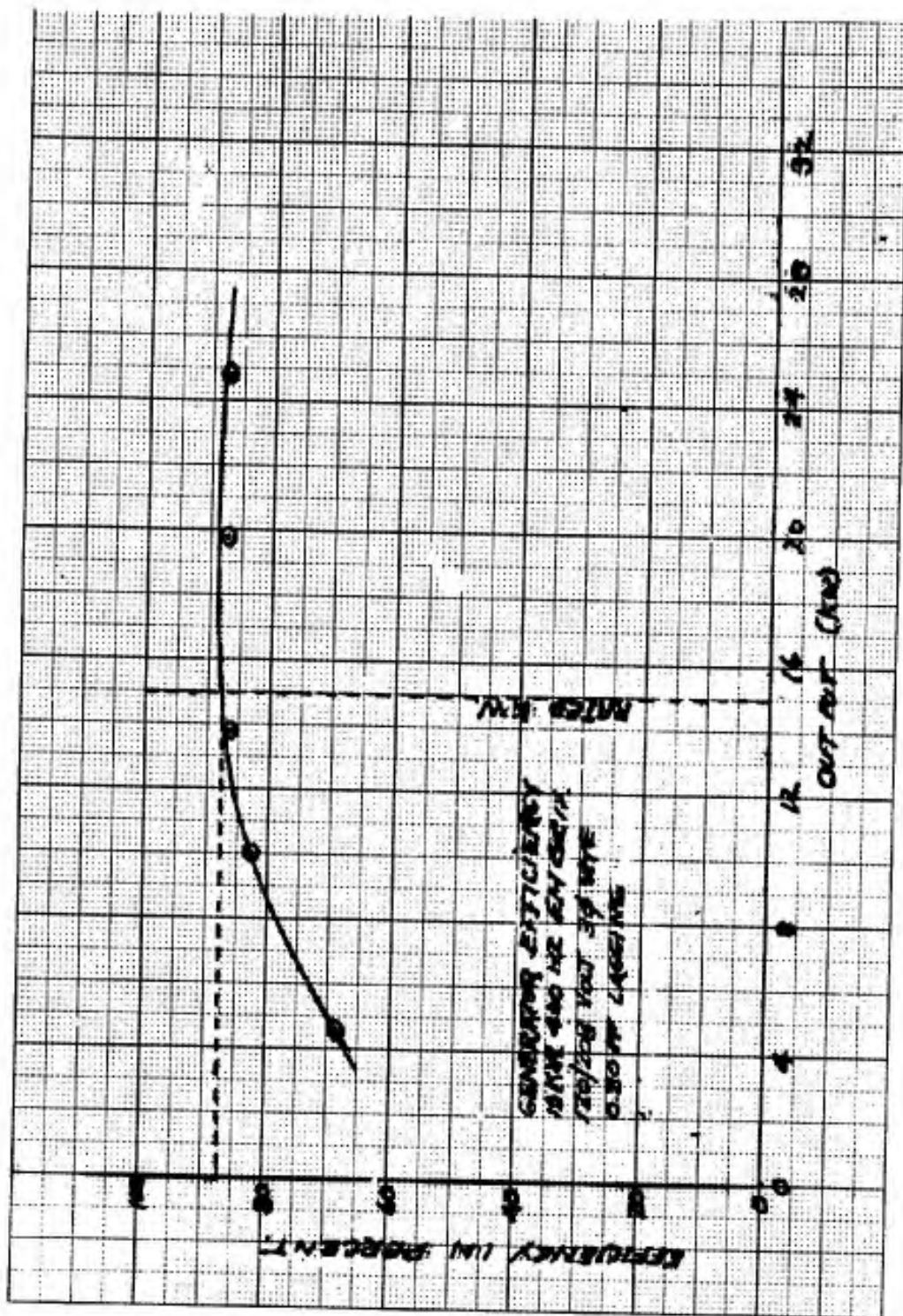


Fig. 9. Generator efficiency, three-phase.

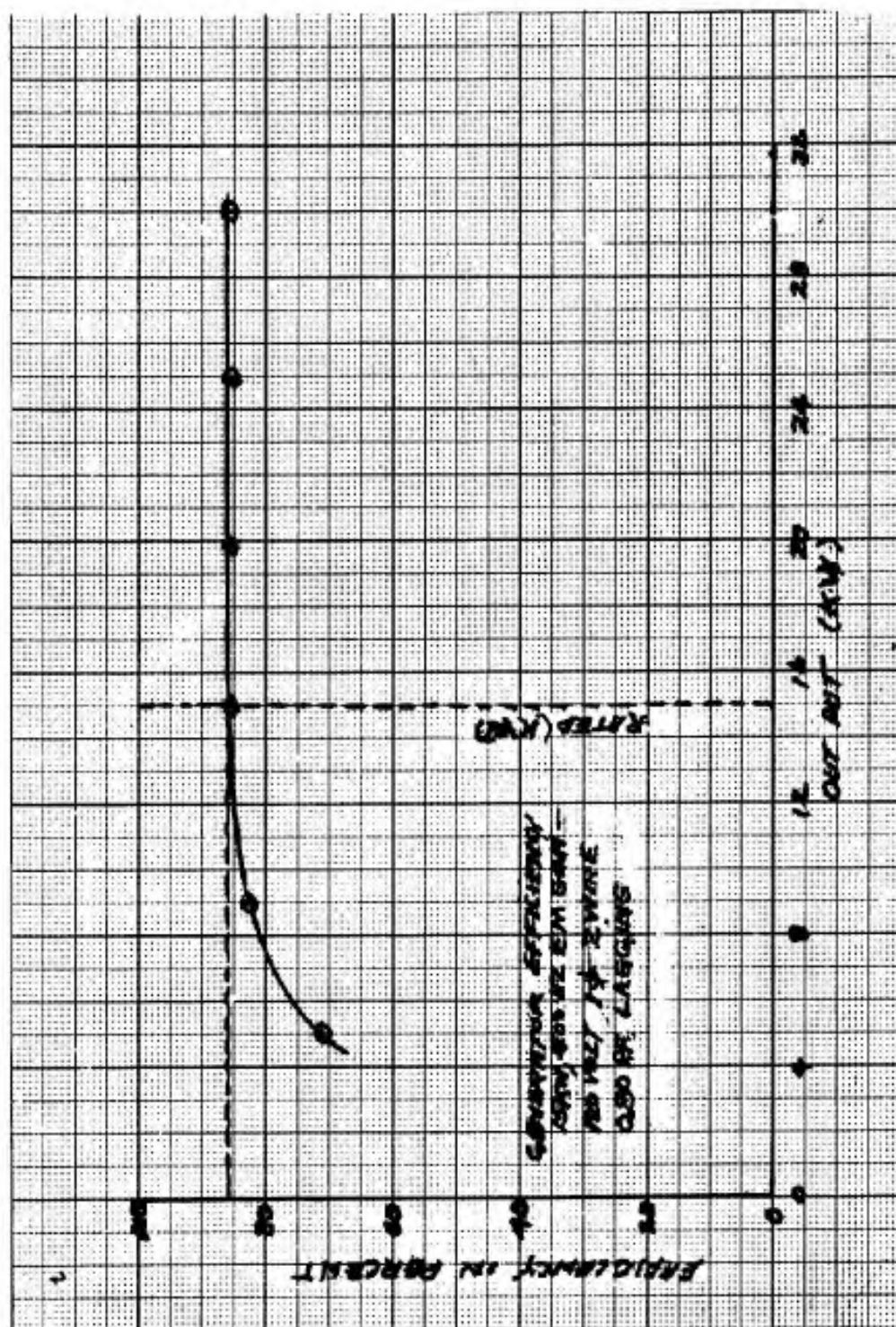


Fig. 10. Generator efficiency, single-phase.

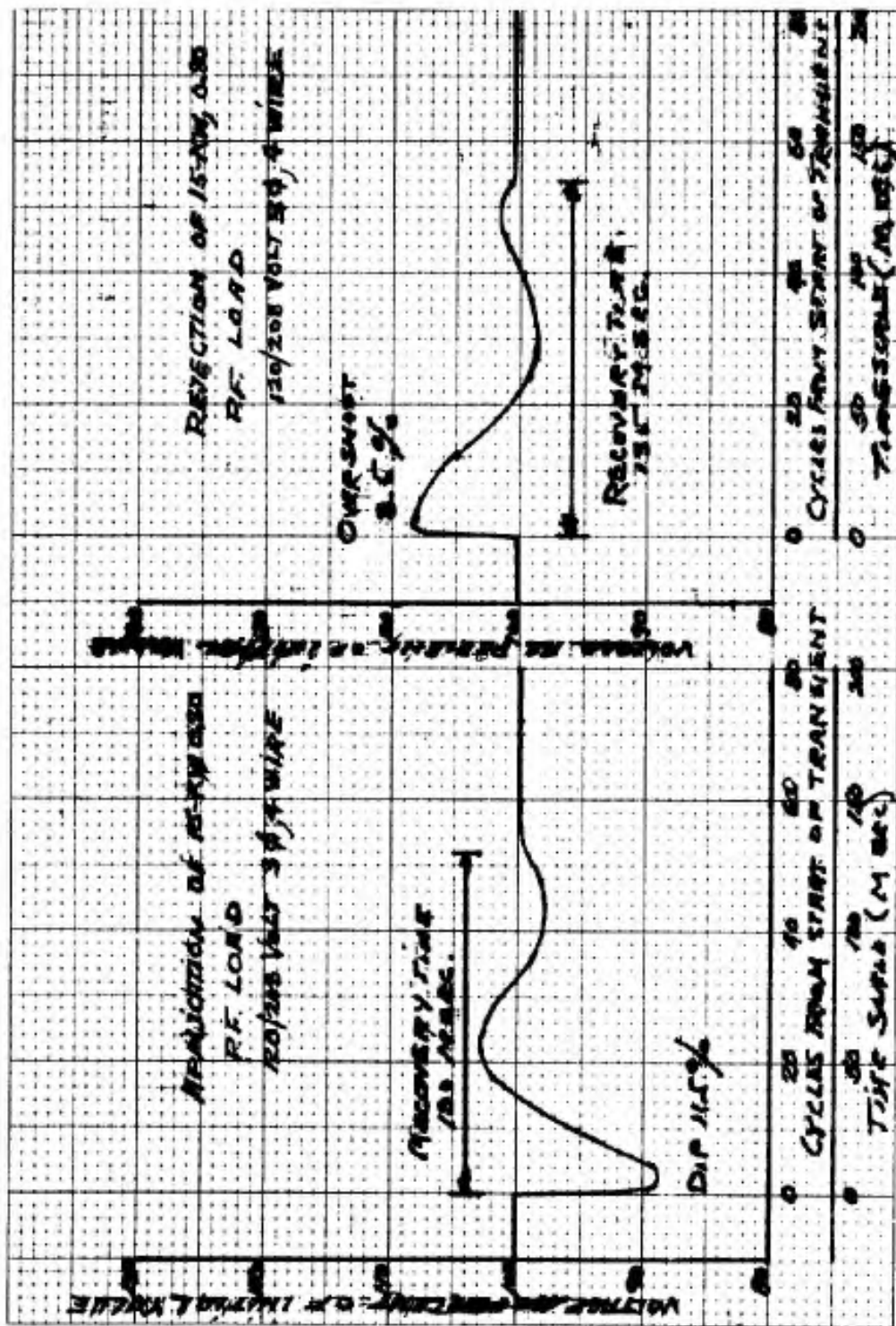


Fig. 11. Rated load, voltage stability, and transient response, three-phase—original CVT's.

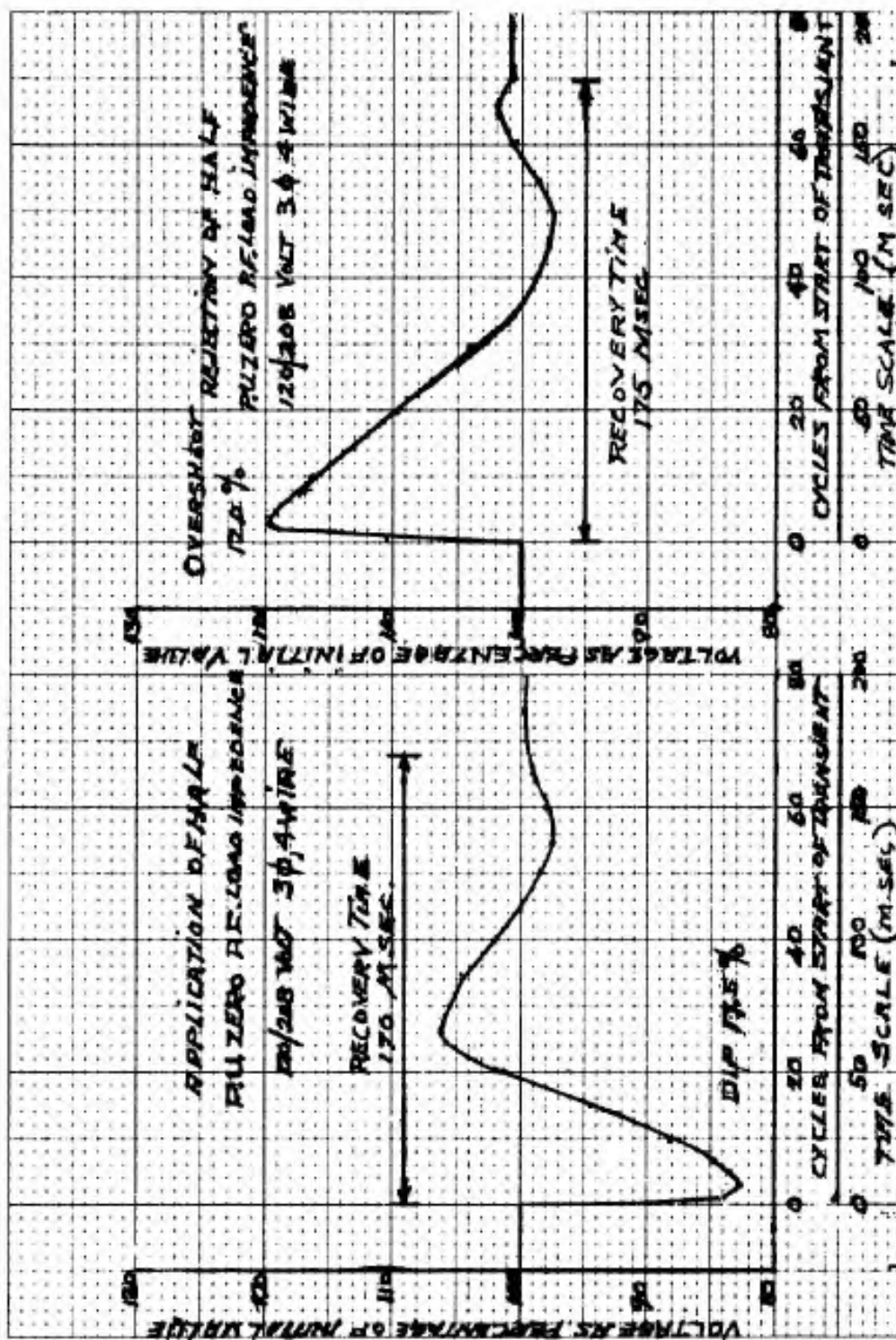


Fig. 12. Zero pf load, voltage stability and transient response, three-phase—original CVT's.

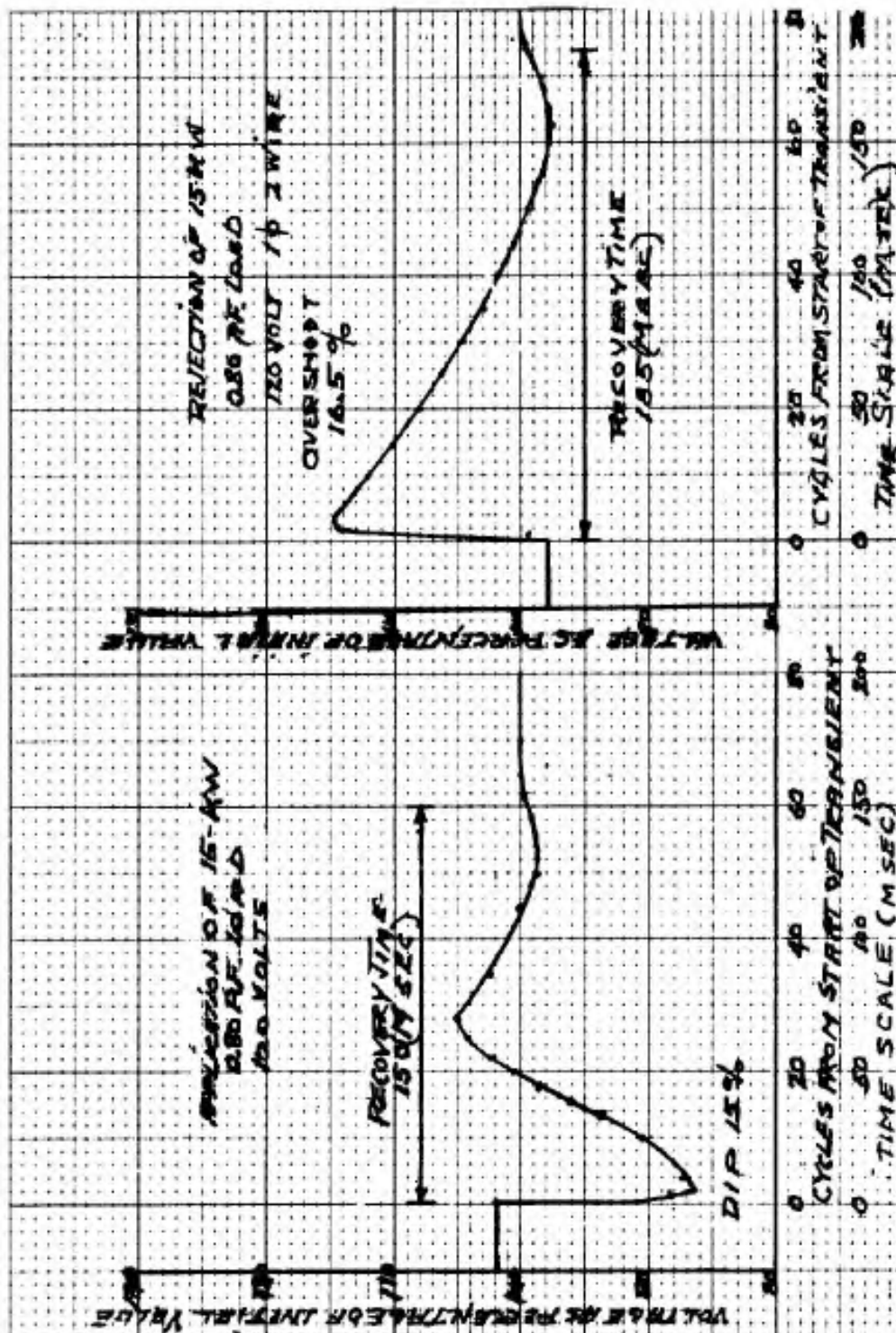


Fig. 13. Rated-load, voltage stability and transient response, single-phase—original CVT's.

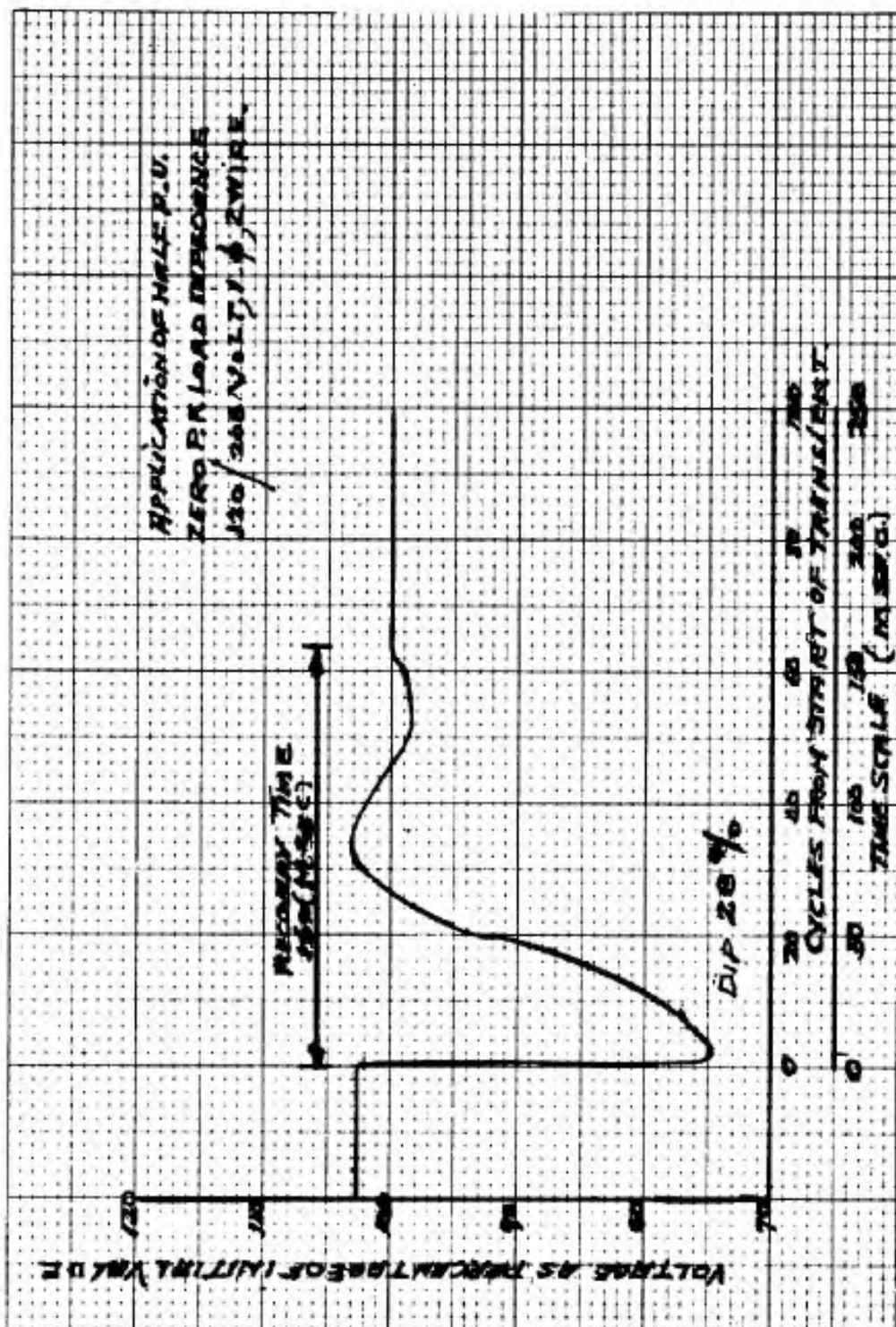


Fig. 14. Zero pf load, voltage stability and transient response, single-phase—original CVT's.

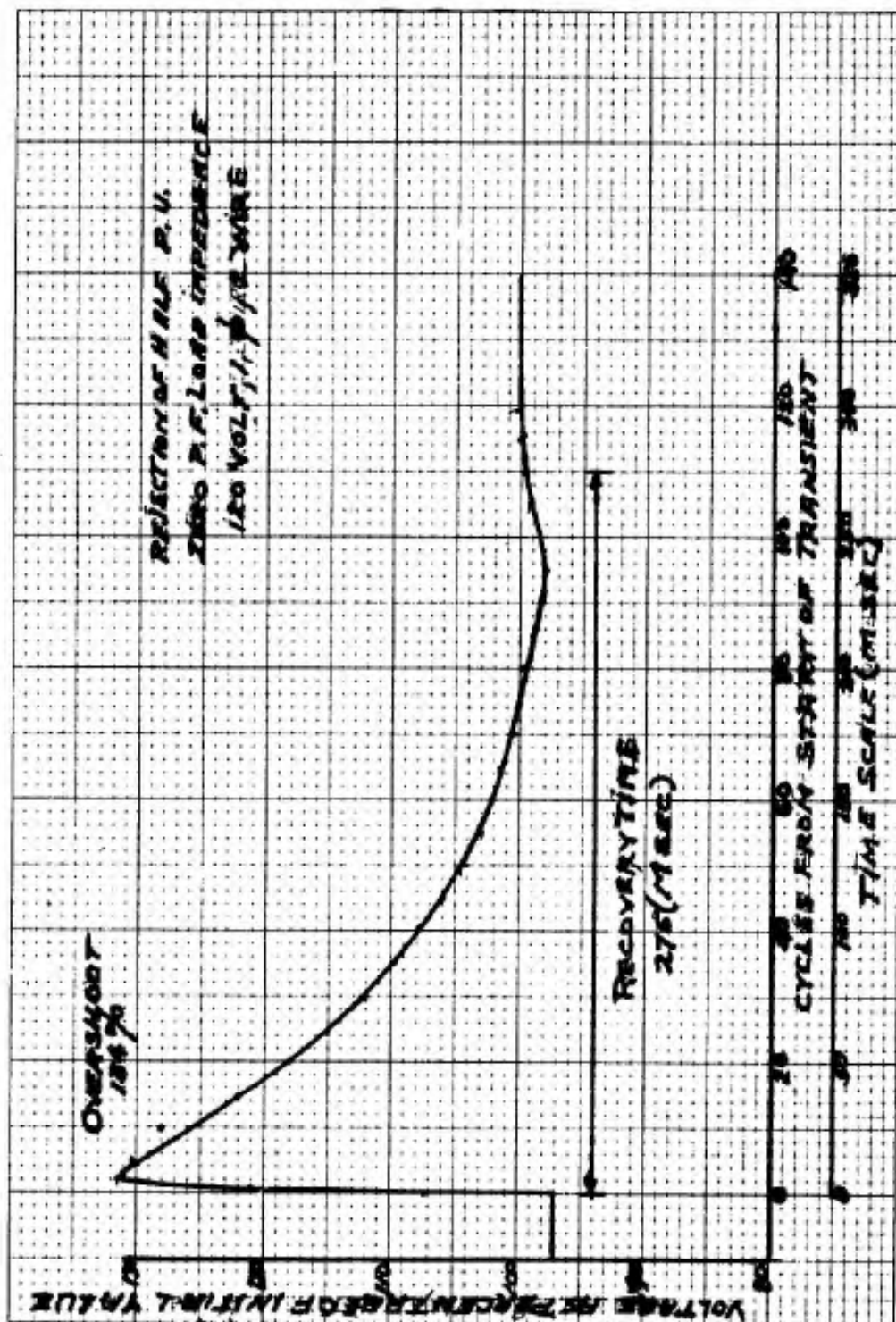


Fig. 15. Zero pf load, voltage stability and transient response, single-phase—original CVT's.

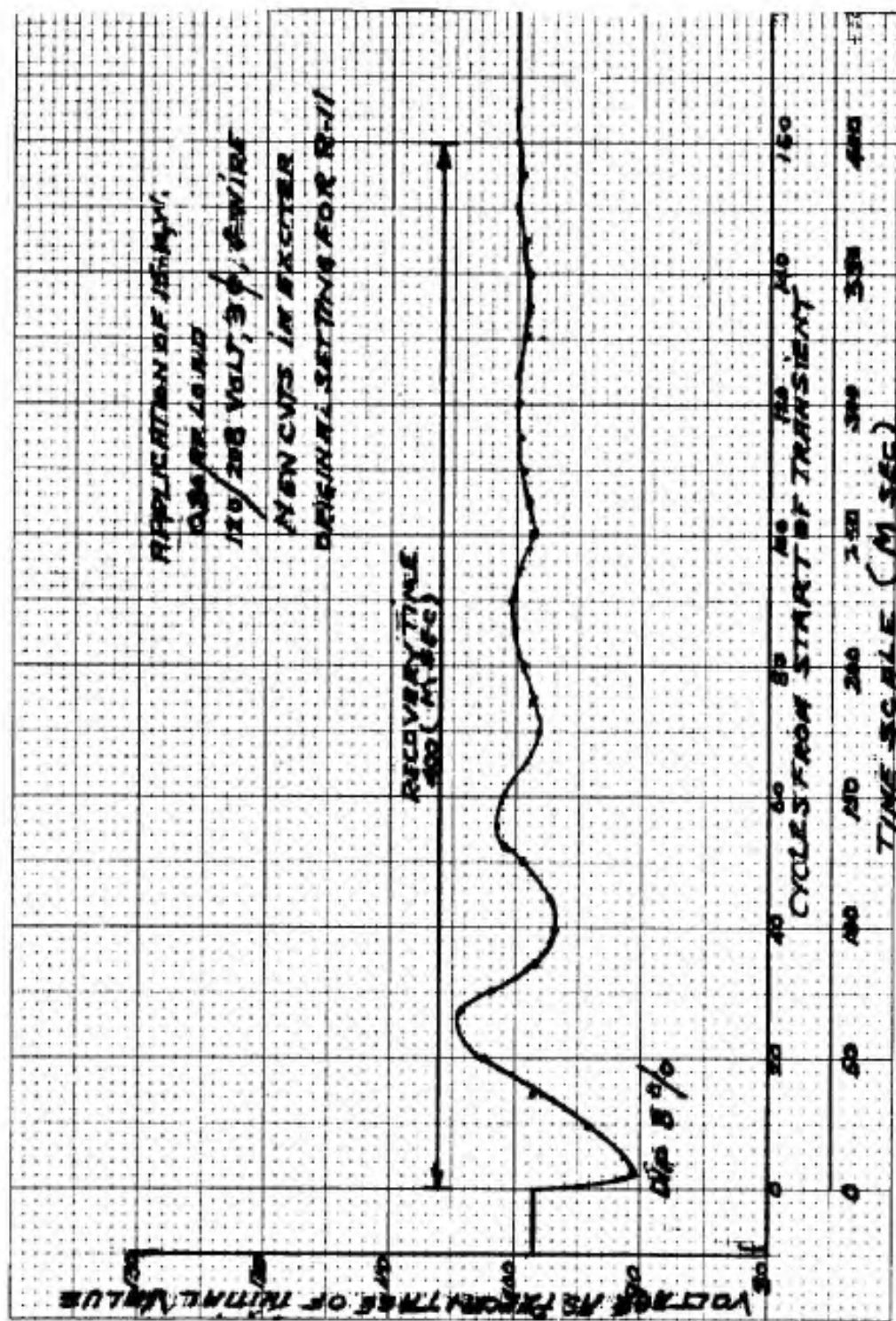


Fig. 16. Rated load, voltage stability and transient response, three-phase—new CVT's (R-11 not adjusted).

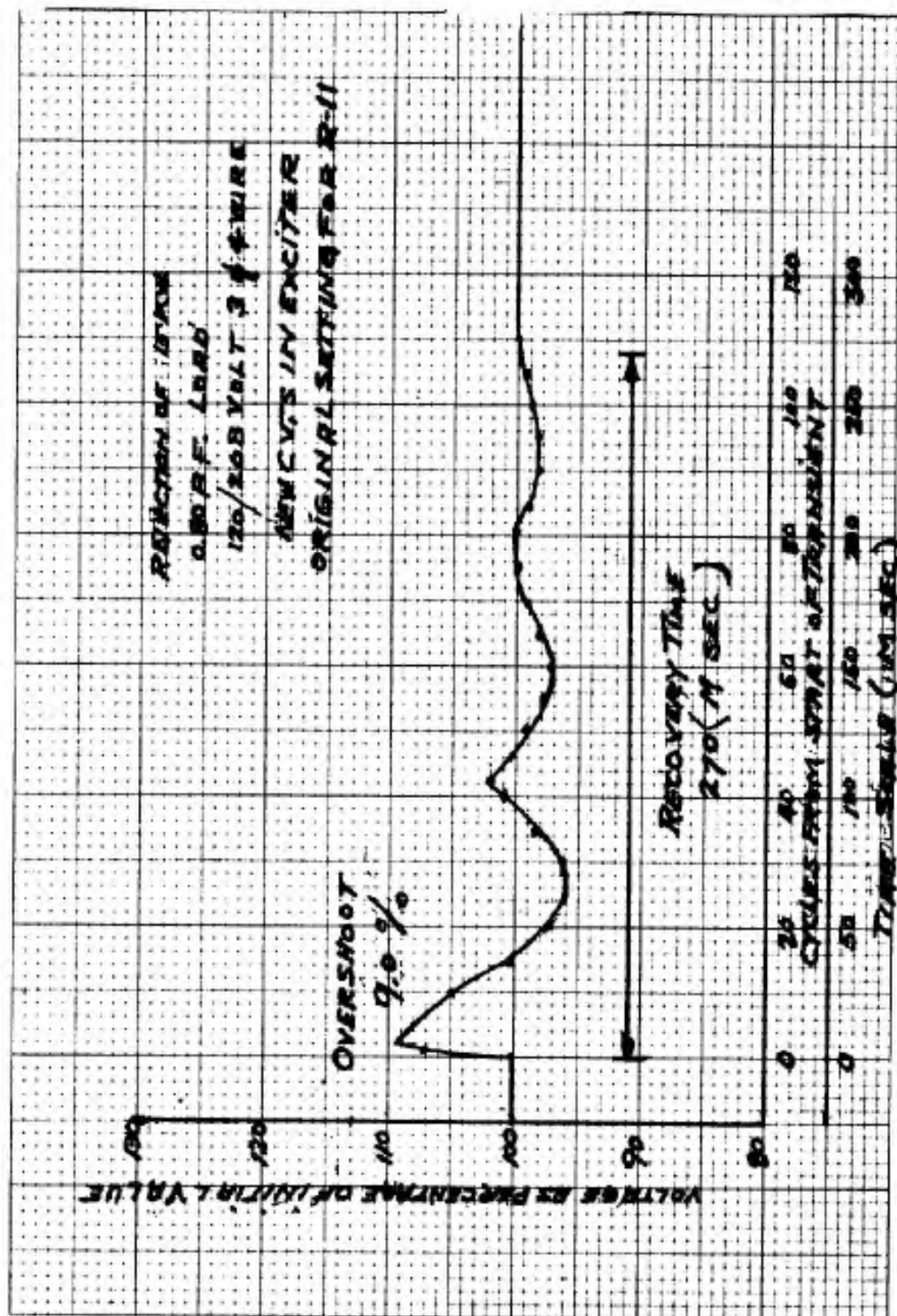


Fig. 17. Rated-load, voltage stability and transient response, three-phase---new CVT's (R-11 not adjusted).

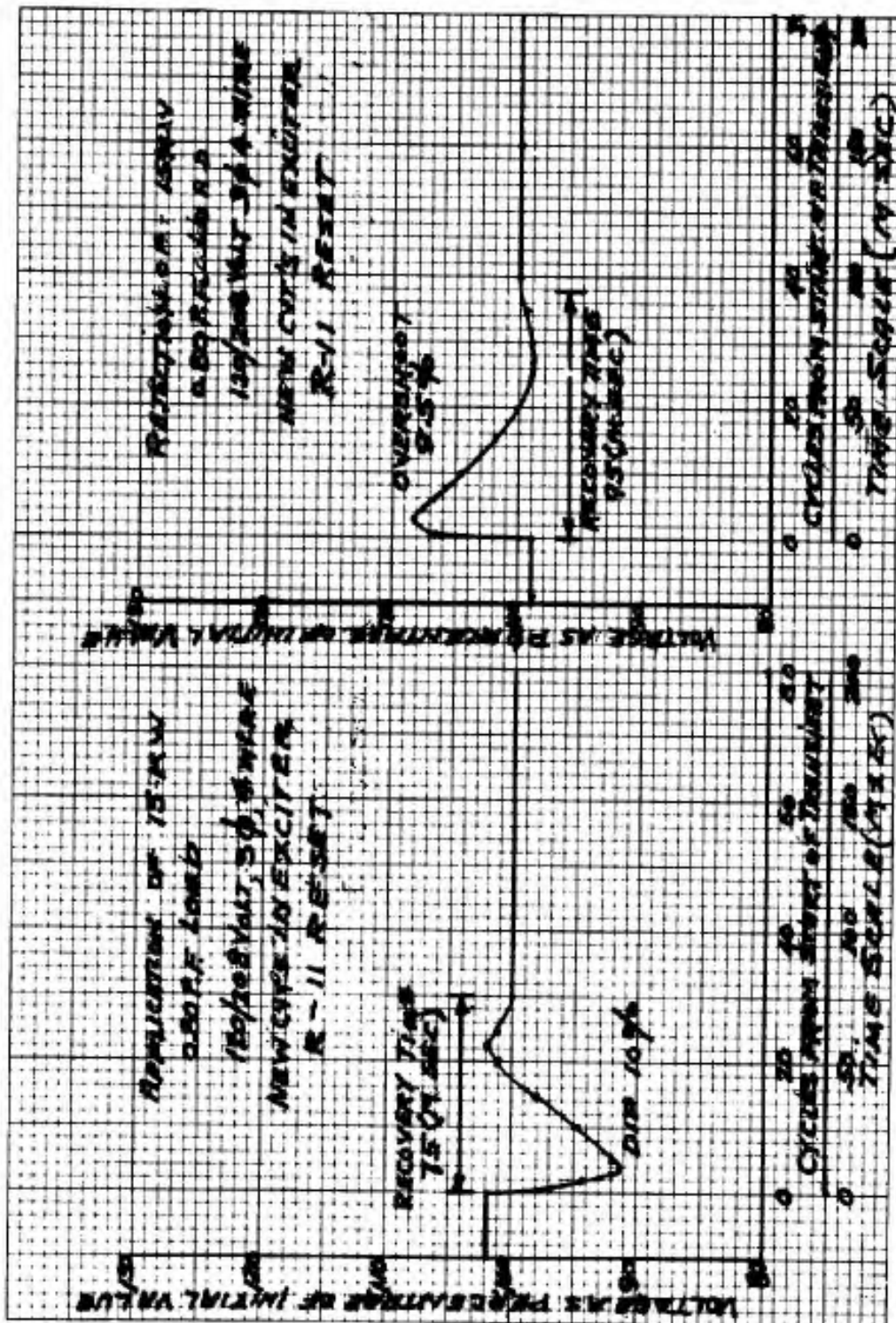


Fig. 18. Rated-load, voltage stability and transient response, three-phase---new CVT's (R-11 adjusted).

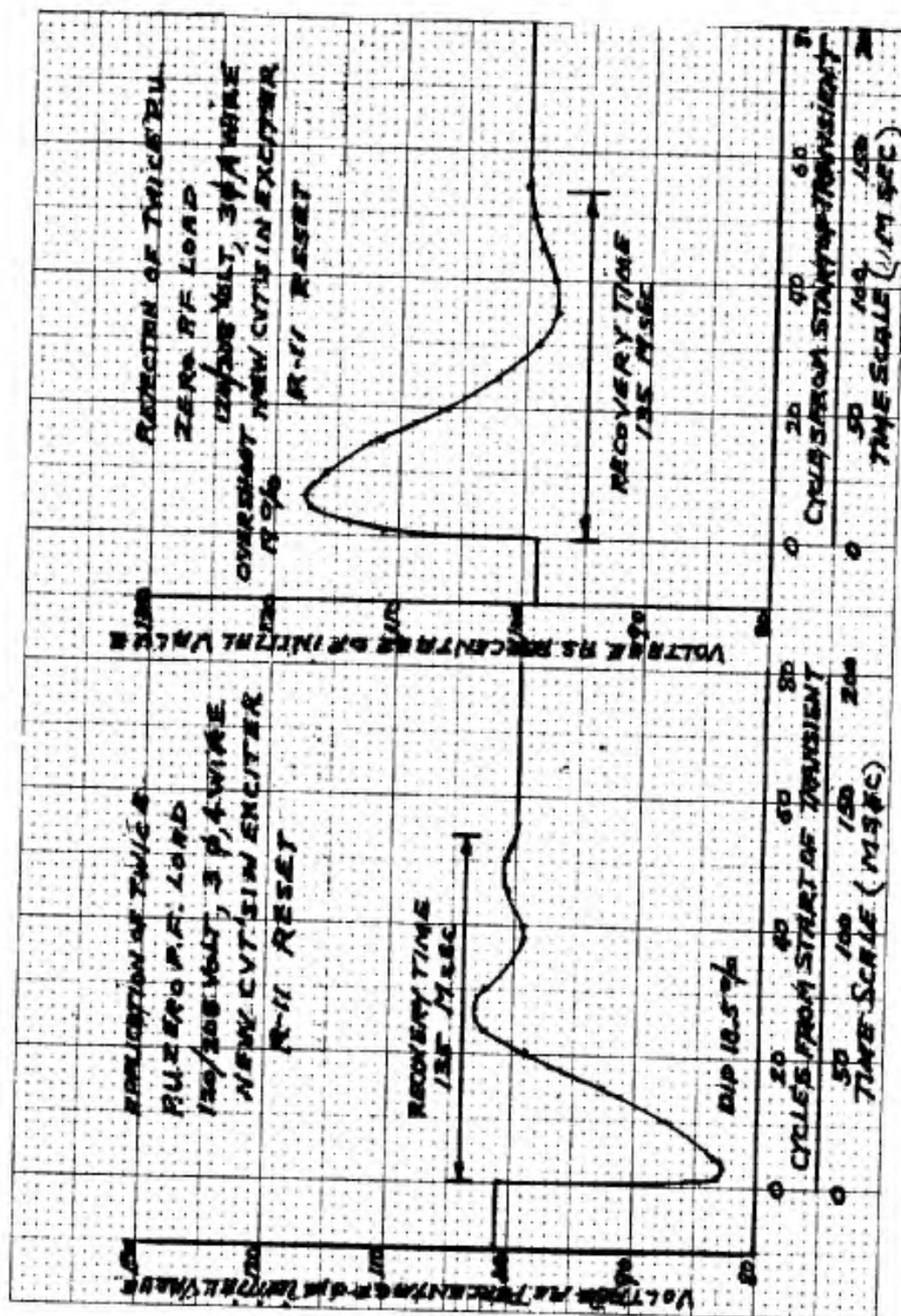


Fig. 19. Zero-pf load, stability and transient response, three-phase---new CVT's (R-11 readjusted).

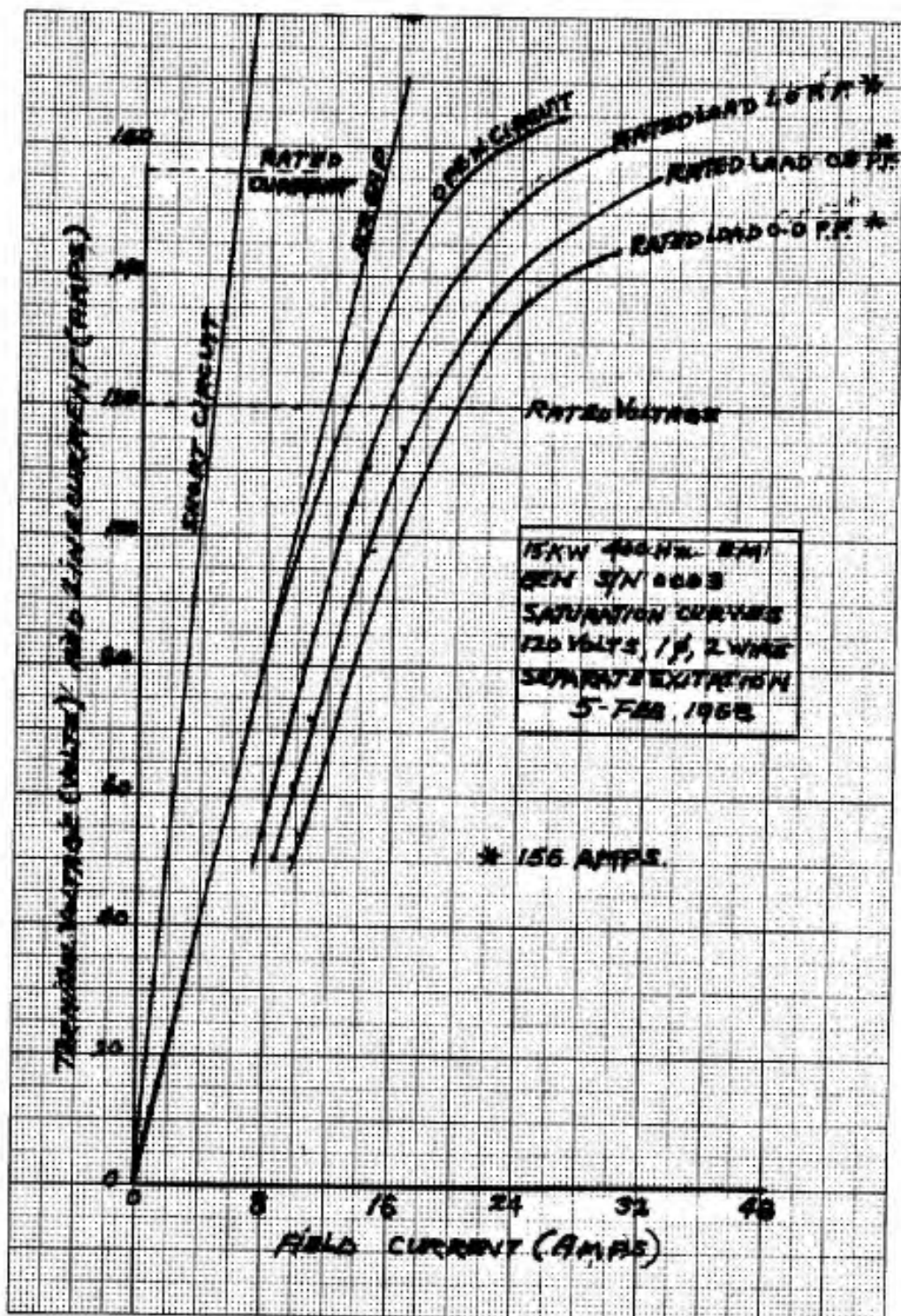


Fig. 20. Saturation curves, three-phase.

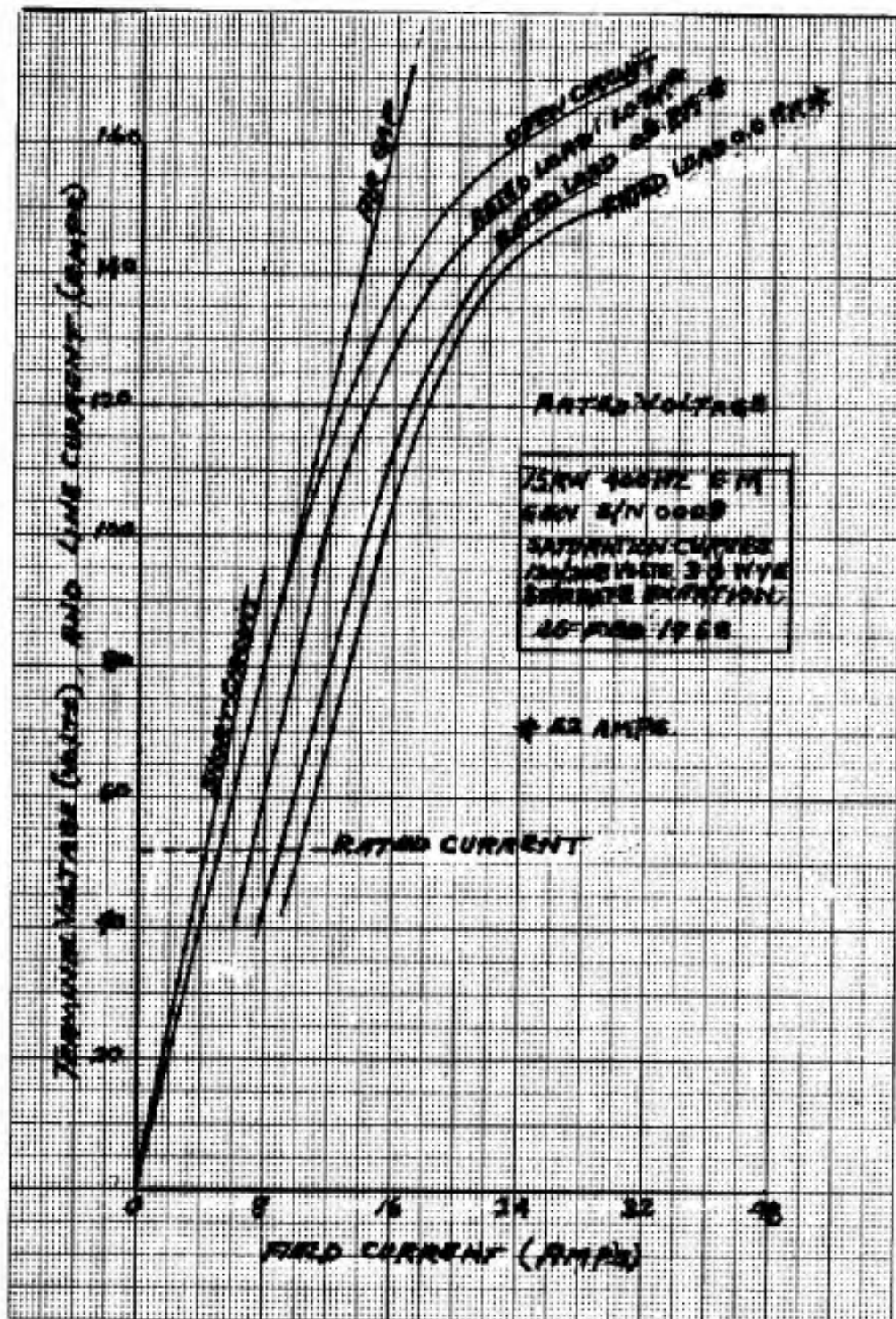


Fig. 21. Saturation curves, single-phase.

(2) Regulator Stability and Transient Response. Results of these tests, on equipment as received at MERDC, are shown in Figs. 11 through 15. After this data was taken, it was learned (at MERDC and also at the contractor's plant) that the voltage-regulator control was excessive on most units being produced; this would not permit adjusting voltage to the specified minimum value. The generator excitation system was designed to operate with a nominal control current of 1.0 ampere. The first production sets had control current as high as 1.80 amperes. This value approaches the output limit of the voltage regulator and does not allow for proper operation. Investigation revealed that an interference occurred during manufacture of the exciter Current-Voltage Transformer (CVT) which introduced an air gap in the laminations. This gap necessitated a higher control current. A correction in manufacturing was made to eliminate the air gap in the CVT's; and regulator stability and transient response tests were repeated at MERDC using an exciter equipped with the new CVT's. Control current was 0.75 ampere for rated generator output voltage, and performance was improved in that the lower limit of the specified range of voltage adjustment could now be obtained; however, the stability after shock loading was relatively poor as denoted by the relatively large number of voltage oscillations which took place after the load was changed. Figures 16 and 17 illustrate this condition. By adjusting the stability resistor (R-11) in the voltage regulator, it was possible to improve stability to an acceptable value. Figures 18 and 19 show results obtained after this adjustment and are the basis of the data included in Table III. As a further check on the effectiveness of the change, two additional sets of the new CVT's were installed in the exciter in turn. Performance was satisfactory and not significantly different.

(3) Saturation Curves. This data was taken (for information) in accordance with procedures in Mil-Std 705. The data is summarized in Figs. 20 and 21.

III. CONCLUSIONS

6. Conclusions. It is concluded that the Hol-Gar Model SP-HF-15 generator set meets the requirements of the applicable Purchase Description and will be suitable for powering the Army, 30-inch, Xenon Searchlight.